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INDIAN FOREST BOTANY.



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MANUAL
OF
INDIAN FOREST BOTANY.

PART I.

MORPHOLOGICAL BOTANY.

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MANUAL OF INDIAN FOREST BOTANY.

PART I.

MORPHOLOGICAL BOTANY.

INTRODUCTION.

THE study of animated nature forms the science of Biology, and

Biology, its sub-division into Botany and Zoology. this is sub-divided into Botany and Zoology, the former dealing with the Vegetable, and the latter with the Animal, Kingdom.

Plants and animals are said to be *organized*, as every individual is formed on a definite plan, and composed

Plants and Minerals, their difference. of one or more organs, each of which has its own special use. Minerals, on the

contrary, may be either *amorphous*, having no definite structure, or *crystalline*, when composed of a number of homogeneous molecules arranged according to a definite geometrical pattern.

Animals are easily distinguished from plants in their highly

Animals and Plants, their difference. developed forms, but in their more simple forms, the two orders pass insensibly the one into the other.

Cells of certain sea-weeds and other lowly organized plants have, in many cases, temporarily, a power of free motion, and hence the main difference between lower animals and lower plants consists in the restraint which a more or less rigid covering imposes on the latter.

Plants are chiefly nourished by matter derived from the earth or atmosphere, from which they appropriate inorganic materials, and form them into structures possessing life, at least for a limited



INTRODUCTION.

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period. Animals, on the other hand, subsist mainly on organic substances, that is, they directly, or indirectly, as in the case of carnivorous animals, appropriate and live on organic vegetable substances, which they have not the power of producing. Water, oxygen and salt, are the principal substances necessary for the life of animals not completely supplied by plants. Thus plants stand between the Mineral and Animal Kingdoms, and convert materials of the one into food for the other.

Animal tissues decompose, as a rule, with much greater rapidity than those of plants, which, as in the case of wood, or cotton fibre, may remain for centuries with hardly a trace of decay. At the same time, vegetable matter, such as that of seeds, when rich in nitrogen, and thus resembling animal tissue, decays rapidly if exposed to moisture and heat.

Vegetable Morphology, or the comparative anatomy of plants, **Morphology.** has reference to their structure.

Vegetable Physiology treats of plants and their several parts in a state of life or action, and has to do with **Physiology.** their *nutrition, growth and reproduction.*

A plant may be defined as a living and organized structure capable of assimilating inorganic matter, **Plant defined.** which it absorbs in a liquid or gaseous state, and differing from an animal in its mode of nutrition.

Exceptionally, certain plants termed *parasites*, obtain a part or all their nourishment from already organized vegetable or animal tissues, or from these tissues in a state of decomposition, **Parasites and Saprophytes.** when they are termed *saprophytes*. The mistletoe is a parasite, and fungi are saprophytes.

The body of a plant is composed of parts with definite *position, succession, structure and direction of growth,* **Member.** termed *members*. Thus stems, roots and leafy shoots, are members.

Members are therefore merely morphological parts of plants. Each member may be adapted for definite physiological work, and as such becomes an *organ* for such work. Thus the leaf is an organ of nutrition, while the flower is an organ of reproduction.

The most important division of the Vegetable Kingdom is that



of *Phanerogamæ*, or flowering plants, in which the organs of reproduction may be readily distinguished, and *Phanerogamæ* and *Cryptogamæ*. it is thus distinguished from *Cryptogamæ*, in which the organs of reproduction are more or less concealed.

Among the lower cryptogams, such as lichens and fungi, there is no differentiation of stem, leaf and root, and such a body is termed a *thallus*. Higher orders of plants have roots, which generally only produce lateral roots similar to one another and to the parent root, but may sometimes give rise to stems, as in the root suckers of sissu and sandal. Stems produce leaves, flowers, fruits and roots, members differing from the parent stem, as well as branches, which resemble it.

The division of *Phanerogamæ* contains almost all important forest plants.

Phanerogamæ are again sub-divided into *Monocotyledonæ*, *Gymnospermæ* and *Dicotyledonæ*, to explain

Phanerogamæ sub-divided into *Monocotyledonæ*, *Gymnospermæ* and *Dicotyledonæ*. which terms, it is better to take concrete examples. When the *pericarp* or outer case of a fruit is ripe, it either opens, so as to allow the seed or seeds to escape by the rupture of the *funicle* which attaches each seed to the pericarp, or it remains closed, and the seeds then only become free by its decay, or after its consumption by an animal. In the former case, the fruit is said to be *dehiscent*, as the pea pod: in the latter case, the fruit is *indehiscent*, as the mango.

The hard outer skin of a seed is termed the *testa*. Inside the testa, we find the *nucleus* containing the most im-

Testa.

portant part of the seed—a little plant in miniature, termed the *embryo*. In the pea, the embryo fills up the whole cavity of the testa, and therefore forms the whole nucleus.

In other cases, as in the seed of the maize, or of a pine, the embryo is surrounded by a substance va-

Endosperm.

riously termed the *endosperm*, the *perisperm*, or *albumen*. The latter term arises from a resemblance to the albumen or white of an egg.

The embryo is composed of a *caulicle*, or little stem and root combined, with one, two or more *cotyledons* or seed-leaves, which may, however, in rare cases be entirely absent.



The cotyledons of the pea are two semi-globose bodies, having little resemblance, if any, to leaves : but we shall afterwards see that cotyledons are in every case actual leaves, when considered morphologically.

Plants which like the pea have seeds with two cotyledons, as a rule **Dicotyledonæ.** belong to the division of *dicotyledonæ*.

In the case of the pea, we find that after germination and bursting of the testa the cotyledons remain in the ground, and do not assume the appearance of leaves, but continue to afford nourishment to the seedling until it is able to look after itself. Such cotyledons are termed *hypogæous*.

If, however, we take a seed of the castor oil plant, we find that the cotyledons force their way above ground at the end of a short stem, termed the *hypocotyle*, beneath which the root proceeds into the soil, while the cotyledons assume the appearance of imperfectly formed leaves.

In *monocotyledonæ*, as in the maize, we find after germination only one cotyledon, a membranous sheath-like leaf, covering a second or a third and fourth leaf, which afterwards protrude beyond it ; each leaf generally becoming larger as it is later formed.

The immature seed in an undeveloped fruit is termed an **Ovule.** *ovule*.

In young pine cones, we may notice that the ovule is merely placed behind a scale of the cone, not enclosed in it, as the pea is in the pod, and owing to this peculiarity of having exposed or *naked* ovules, pines, firs and other conifers or cone-bearing plants, as well as other allied plants, are termed **Gymnospermæ.** If we examine a pine seed, we find that the embryo has more than two cotyledons, and as this, with some exceptions, is the rule with *gymnospermæ*, they are sometimes termed *polycotyledonæ*.

The most important forest plants are found amongst the *dicotyledonæ* and *gymnospermæ*, as *sál*, teak and deodár.

The palmyra and other palms, as well as bamboos and grasses, belong to the *monocotyledonæ*.

After germination, the caulicle gives rise to the *plumule* and



radicle, the former proceeding upwards to form the stem with its branches and leaves, flowers and fruits, while the latter proceeds downwards into the soil and gives rise to roots and rootlets.

As already mentioned, the short stem below the plumule and between the cotyledons and the root is termed the *hypocotyle*.

The following statement will be found useful :—

Seed.	{	Testa and Nucleus.	{	Endosperm.	{	Plumule.
				Embryo.		Caulicle.	Hypocotyle.
						Radicle.
						Cotyledons.

The endosperm may be absent, and the cotyledons from 0 to 15, or even more.

Exceptionally, a dicotyledon may have one or no cotyledon, and a gymnosperm may have two. We shall see further on, that there are other important characteristics in the structure of these divisions of the Vegetable Kingdom.

The plumule generally grows upwards into a stem and leaves,

Ascending and descending axes. forming the *ascending axis* of the plant ; while the radicle generally penetrates into the ground and forms the *descending axis* of the tap-root and its branches, which is frequently undeveloped in monocotyledons, its place being taken by *adventitious* roots from the base of the plumule.

We cannot make a separate order of *polycotyledonæ*, as gym-

Gymnospermæ, a sub-division of **Dicotyledonæ**. nosperms connect the higher order of cryptogams with phanerogams, but have more analogy in the structure of their wood with dicotyledons, than with monocotyledons, which may be considered to stand on an isolated line from dicotyledons and gymnosperms, the latter being a sub-division of the former, as shown in the annexed table—

Phanerogamæ	{	Monocotyledonæ.
		Dicotyledonæ.
Cryptogamæ.		Gymnospermæ.

The term *Angiospermæ* is used to include all plants with enclosed *ovules*, and including such distinct divisions as *Monocotyledonæ* and *Dicotyledonæ*, as opposed to *Gymnospermæ*, is not really well founded.



CHAPTER I.

THE CELL, ITS NATURE.

SOME of the simplest plants with which we are acquainted, the yeast plant for instance, consist, in their earlier stages, of a single minute vesicle enclosing semi-fluid albuminous contents, and such structures are termed *cells*. A cell, in its living state, generally consists of three parts, the *cell-wall*, the *protoplasm*, including the *nucleus*, and the *cell-sap*.

Cell	{	Protoplasm and nucleus.
		Cell-wall.
		Cell-sap.

The cell-wall may be absent, but the protoplasm must be present in a living cell.

Some cells, termed *primordial-cells*, are naked masses of protoplasm, which being the essential part of a living cell, will be first described. From **Primordial-cells.** cells, which have ceased to live, the protoplasm may have entirely disappeared.

Protoplasm is endowed with internal forces and with a variability unknown in any other substances. It is at present recognized as the origin of all processes of organic life. Its consistence varies greatly, but it commonly appears as a soft, plastic, semi-fluid, nitrogenous substance, containing water and mineral matter, and at one time or other, all the chemical substances of plants. It resembles albumen, coagulating at a temperature of 50°C. if alcohol or dilute acids are applied. Iodine and Schultz's mixture* colour it yellow or brown, and concentrated hydrogen sulphate colors it rose-red.

The softness of protoplasm depends on the quantity of fluid it

* The composition of Schultz's mixture is given on pages 22—23 of Bower and Vine's Practical Botany. It furnishes a test for cellulose, starch, liguose, protoplasm, &c.



contains, which increases as the cell becomes older, and unless supplied with water it remains dormant. In hard seeds, such as those of the date palm and vegetable ivory (*Phytelphas macrocarpa*), the protoplasm is practically solid, but becomes soft by the absorption of water, when the seed germinates. Young cells are often completely filled with protoplasm, and corn, peas and beans are highly nutritious, on account of the nitrogenous matter contained in their protoplasm. As the cells become older and larger, the protoplasm merely lines their walls and forms threads across the cell cavity, from one wall to another, and it is generally absent in very old cells, which, we shall see further on, cease to live, after their protoplasm has been absorbed by surrounding younger cells, and merely contain cell-sap, crystals, or air within their cavity.

Old grass after it has seeded is no longer nutritious, the protoplasm and most of the nutritive matter having passed into the seed. It has recently been discovered that protoplasm is continuous throughout the living part of the plant, passing from cell to cell through minute apertures in the cell-wall. All the living processes in plants depend on the presence of protoplasm.

One of the most important substances contained in protoplasm is termed *chlorophyll*, being the green coloring matter so common throughout the Vegetable Kingdom. It is always united to definite portions of the protoplasm in all cells in which it is found. Every chlorophyll body consists of a protoplasmic granule, and of the coloring matter, which may be removed by alcohol, ether, or some essential oils, leaving the protoplasm colorless behind. The coloring matter is extremely small in quantity, and the chlorophyll granules are always embedded in colorless protoplasm, and are not in contact with the cell-sap.

With very few exceptions, starch grains arise in the chlorophyll bodies, being first visible as points, gradually increasing in size, until they may so fill up the space of the granule, that its green substance is represented by a fine coating over the mature starch grain. Even this coating disappears under certain circumstances, as in old yellow tobacco leaves, in which the starch has entirely replaced the chlorophyll. Sometimes drops of oil are also found



in the chlorophyll grains instead of starch, but this depends on light, temperature and other circumstances.

Sooner or later the chlorophyll bodies are again absorbed, as in leaves about to fall, from which generally all the protoplasm is transferred to the buds, branches and stem of the plant.

Chlorophyll becomes red or yellow by *degradation*,* as in the bright yellow blossom of cucumbers and in ripening fruits.

In the case of falling leaves, the colour is due to an absorption of the chlorophyll granules with the rest of the protoplasm, and the appearance of a number of yellow granules.

In old dying leaves, the chlorophyll is dead or absent, but in young leaves it is frequently concealed by a red coloring matter, termed *erythrophyll*.

The green of the chlorophyll in young shoots of the mango, for instance, is frequently masked by a reddish colouring matter, which may be dissolved by cold fresh water, leaving the green chlorophyll apparent. A portion of the protoplasm occasionally assumes crystalline forms, usually colourless, sometimes coloured : but never green. They are capable of absorbing water and swell up enormously in certain solutions, and are termed *crystalloids*. We also find, especially in seeds, masses of *aleurone* in protoplasm. This is a nitrogenous substance mixed with starch and oily matter, and is a reserve material for the future supply of protoplasm to growing parts of a plant. Living protoplasm contains granules which are in constant motion, the whole mass of the protoplasm rotating as well.

A cell may, therefore, be considered alive, as long as it contains living protoplasm, which is conveyed through the walls of dying cells to the still growing parts of the plant. We find in certain cryptogams that *primordial-cells*, termed *antherozoids*, have the power of independent motion, after escaping from the parent plant, and in this way resemble animals. Besides this power of motion in certain cases, living cells are also capable of expansion, and of producing new cells.

Cells without living protoplasm, which are really dead, may

* *Degradation* is a process by which a substance in a plant useful for its development becomes converted into one useless for this purpose, as in the conversion of cellulose into gum.

acquire thicker walls by a process we shall study further on, but are incapable of division into new cells, or of further expansion.

A somewhat solid rounded body included in the protoplasm, and resembling it in its composition, is termed the *nucleus*. It often contains one or two,

and sometimes more, granules, termed *nucleoli*, which, however, are not found in the lower plants. The nucleus and the nucleoli are embedded in the mass of the protoplasm of a cell.

Cell-wall. The firm elastic outer coat of a cell is termed the *cell-wall*.

The young cell-wall is composed of cellulose ($C_6 H_{10} O_5$), a

Cell-wall, its composition. substance isomeric with starch, dextrin, inulin, and arabin.

Cellulose may be tested by its blue color, when treated with hydrogen sulphate and iodine; or with

Cellulose. Schultze's solution, while starch becomes blue with iodine alone. The cell-wall of certain lichens, however, is coloured blue by iodine alone.

When the cell-wall subsequently thickens, other substances besides cellulose are introduced into it, and impart certain colours to the cell-wall, as we see in woods. Pure cellulose is colourless, as may be seen under the microscope in the epidermis of the agave.

Cells of the most perfectly developed forms are found in certain cryptogamous families of *Algae* or sea-weeds, where the separate parts of the cell-wall, the protoplasm and the bodies contained in it, show a variety of structure not found simultaneously in other cells.

Frequently, certain cells in phanerogams never attain a full development, but give rise to new cells by processes of division, which may become more highly developed than the parent cells.

The watery fluid occupying the cell cavity of older cells and permeating the protoplasm and the cell-wall of all cells is termed *cell-sap*, and is

Cell-sap. destined to assist in the growth of new cells by holding in suspension or dissolving the materials it encounters, and transporting them from one part of the plant to another, also by combining with other substances to form new constructive material.

THE CELL, ITS NATURE.

Without a sufficient supply of cell-sap, a living cell remains inert, as in the case of dry seeds.

One of the most important of the substances dissolved in the cell-sap is *inulin*, a form of starch soluble in cold water. Large quantities of inulin are found in the tubers of the Jerusalem artichoke.

Plants increase in size by the formation of new cells and the growth of already existing ones, owing to the expansion of their cell-walls. In many cases, as in the growth of *fungi* or of *bamboos*, the production of new cells and expansion of already existing ones is very rapid. A young bamboo culm may grow to a height of 60 feet in a few weeks and, in a single night, a large mushroom grows from a small under-ground bud.

The formation of a new cell always coincides with the re-arrangement of a protoplasm mass round a new centre. *"The material required is always afforded by protoplasm actually present, and the newly constituted protoplasm mass, sooner or later, clothes itself with a cell-wall."*

The formation of new cells does not always result in an increase in the number of cells in a plant or member, and we may distinguish *three* types of cell formation—

- (i). The renewal, or *rejuvenescence* of a cell, being the formation of a single new cell, from all the protoplasm of one already existing.
- (ii). *Conjugation* of two or more protoplasm masses to form a new cell.
- (iii). Multiplication of cells, by the formation of two or more protoplasm masses, out of one already existing.

The two former cases occur in the reproduction of cryptogams, and need not be discussed here.

As regards *multiplication of cells*, two cases must be distinguished, according as only the protoplasm, or the whole mass of the mother cell is converted into new cells. The former process is termed *free cell formation*, and is generally connected with the reproduction of cryptogams, but also occurs in the formation of the embryo of phanerogams, and in it, portions of the protoplasm and of the



nucleus of the mother cell become rounded, developing walls and separating from the general mass within the wall of the mother cell, which persists for a longer or shorter period round these young cells.

The latter form of multiplication of cells is termed *cell-division*, and is far the commonest of all in the

Cell-division. Vegetable Kingdom, and occurs in all cases of cell formation which accompany growth. In it, the parent cells are sub-divided in such a manner, that the resulting cells resemble them, and are capable of developing into any required form. The entire protoplasm of the parent cell divides into two or more masses by the protrusion into it of the cell-wall.

Cell-division may be considered under two heads—

(i). The formation of reproductive cells.

(ii). Vegetative cell formation.

In (i) the formation of *spores* of the higher cryptogams, and in the *pollen* grains of phanerogams, the **Formation of reproductive cells.** parent cell becomes divided into four parts either at once, or by repeated divisions.

In many *fungi*, certain reproductive cells are produced by a budding in the mother cell, the daughter cells being ultimately separated by a septum, as in the yeast plant.

(ii). In *vegetative cell formation*, the protoplasm of the mother **Vegetative cell formation.** cell is divided into two parts, either by a gradual formation of a wall of partition, or the latter is formed all at once, as in the higher plants.

The former kind of cell formation was the first that was noticed by Mr. Mohl in 1834. In it, we find that **Gradual formation of a wall of partition.** the cell-wall gradually protrudes more and more into the protoplasm of the interior,

at length dividing the latter into two parts, and thus forming two cells out of one. This is readily seen in *spirogyra*, a cryptogam found in fresh water. This process also referring to cryptogams is of no great importance for us, and we go on to the last case, in which the partition is formed all at once.

Here the partition wall, when first visible, appears as a thin **The partition wall formed all at once.** membrane of cellulose stretching across the mother cell, and dividing the pro-



toplasm into two masses, and this form of cell division is found in all the higher orders of plants.

One of the best examples of this kind of cell division occurs in the cambium zone of trees and shrubs, and will be studied further on.

The growing cell-wall is composed of cellulose and water, and of certain mineral matters, which yield the ash left after the combustion of vegetable matter of any kind, when the organic substances of the wall have been volatilized.

Molecular structure of the cell-wall.

The solid material of a cell-wall is, therefore, composed of different substances, which may be considered as small *mycellæ* invisible by the highest magnifying power.

A mycella is an extremely minute *lamina* composed of several molecules of dry substances. It is this combination of *laminæ* of solid material with the fluid which surround them, which gives the characteristic softness and flexibility to organic substances.

Intussusception.

In the cell-wall, it is clear that, the *mycellæ* of different substances are placed side by side, and are separated from one another by the cell-sap, which may be more or less abundant in the cell-wall, and the more cell-sap is present, the greater is the distance apart of the *mycellæ*. In the bamboo, for instance, besides organic matter, large quantities of silica are found, and if a bamboo be burnt so that all the organic matter in it is vapourised, we find a complete skeleton remaining in silica and other mineral matter: the only loss being the weight of its compounds of C H O and N, which have been vaporised chiefly into carbon dioxide, (C O₂) and water, (H₂ O), by the combustion. But, however close in the cell-wall the *mycellæ* may be together, there is always room for water to penetrate between them, and the rigidity of herbaceous members of plants is due to the presence of cell-sap between the *mycellæ* of its cell-walls forcing them apart.

A cell-wall gorged with sap is said to be *turgid*, and *flaccid* if the opposite be the case.

The turgidity of cell-walls, when sufficient cell-sap is present, is readily seen in the case of a potted tobacco plant placed in the sun for a short time, until the soil in the pot is dried up, when a



general drooping of the plant occurs, termed *wilting*, the plant being restored to its former condition by a timely supply of water.

The growth of cell-walls is due to a process termed *intussusception*, which is the intercalation of new mycellæ of matter between those already existing.

Intussusception differs entirely from the growth of crystals, when external layers of matter are continually deposited on a nucleus of the same or some other substance.

It is evident that, without sufficient cell-sap within the cell-wall, growth is impossible, as unless the existing mycellæ are sufficiently separated to allow room for fresh mycellæ between them, intussusception cannot take place, nor can a constant current of the cell-sap conveying new mycellæ to the points of growth occur.

We have all observed the rapid growth of vegetation during the monsoons, and at other seasons on irrigated lands ; whereas in the dry season, without artificial supplies of water, growth ceases in the case of all but deep rooted plants, such as the *sál* tree, the tap root of which goes down to a perennial water stratum at a depth sometimes of 50 or 60 feet below the surface of the soil. We can now understand why the growth of cells cannot take place without a constant supply of water.

Young cells have cavities completely filled with protoplasm, and

Vacuoles.

very thin cell-walls ; cell-sap of course must be present, though sometimes, as in vegetable ivory, in very minute quantities, but it is transfused throughout the mass of the protoplasm, and of the cell-wall, and is not accumulated in the cavity. As the cell-wall expands, however, it also thickens, and certain gaps appear in the protoplasm, which become filled with cell-sap, and are termed *vacuoles*. These ultimately coalesce to form a central cavity surrounded by the cell-wall, which is then merely lined with protoplasm.

The life and growth of a cell-wall only continue whilst its inner surface is in contact with protoplasm.

Changes in composition of the cell-wall.

When the cell dies, the cell-sap, as well as the protoplasm, disappear, and air or crystals alone occur in the cavity. The latter is also frequently almost closed by the thickening of the cell-wall. As stated before, the unthickened *primary cell-wall* is composed of pure, colourless,

transparent, elastic cellulose, insoluble in water, though readily permeable by it. Besides cellulose, we find in the cell-wall water and certain incombustible mineral constituents which form the ash when the plant is burnt.

As the cell-wall becomes older, its chemical composition may alter, and it may become either—

Ligneous, Mucilagenous, Suberous, or Cuticular.

Lignification or impregnation with *lignose* ($C_{18} H_{26} O_{11}$) as in the walls of woody fibres, increases the hardness of the cell-wall, diminishes its flexibility and extensibility, and renders it more permeable by water, without swelling considerably. Lignose is coloured yellow by hydrogen sulphate and iodine and by Schultze's mixture, and dissolves in concentrated hydrogen sulphate. Cellulose is also converted into *glukodrupose*, ($C_{24} H_{36} O_{16}$) found in stones of the peach and other fruit trees, and in the fruit of the pear.

Conversion into *mucilage* renders the cell-wall capable of absorbing large quantities of water, increasing its volume, and rendering it gelatinous. Mucilage turns yellow with iodine and hydrogen sulphate. Mucilage may be readily observed in the case of the seeds of the sain (*Terminalia tomentosa*), also in the small black seeds called *tukam belonga*, which swell up and form a jelly in cold water.

The cell-wall is sometimes cuticularized or converted into *cutin*, *cork*, *suber* or *periderm*, a very light elastic substance, scarcely permeable at all by water, and found in the bark and cuticle of plants, and also as a covering over wounds.

The uses to plants of these various changes can be at once perceived by taking simple illustrations. The crown of a forest tree is at a great height above the water in the soil, and yet this water reaches it readily by passing along its permeable *ligneous* stem.

Seeds frequently contain *mucilage*, which swelling up, when they come in contact with a wet soil, forces open the hard testa, and in cases of scanty rainfall during germination, preserves sufficient moisture around the embryo, to assist its future growth.

Cork being impermeable by water protects the stem of plants from rain, &c., which would otherwise penetrate the bark and wash away much nutritious matter.

If a cell were not acted upon by surrounding cells or other pressure, its external shape would be *spherical*, and we find that the lowest plants, such

Form of cells.

as the yeast plant, have more or less spheroidal cells.

Owing, however, to the pressure arising from the growth of contiguous cells, their walls tend to become flattened, and if there be a greater or reduced pressure in any particular direction, the cells generally become *tabular*, as in cork cells, or greatly elongated in comparison with their breadth, when they are termed *fibres*, as in the bark of plants. If the pressure were applied equally in all directions, and the cells were all originally of the same size, they would be *dodecahedral*, owing to the action of a well-known physical law. If the pressure be uniform in two directions, at right angles to one another, and much less in a third direction and at right angles to the planes of the other two, the cells would become hexagonal prisms, resembling the wax-cells of a honey-comb, and basaltic columns. We find flattened hexagonal prismatic flakes of bark in the slow growing box tree, the form of which is due to a similar cause.

When first formed, cells are generally extremely minute, and may remain so during their whole life, but in most cases they increase considerably in size and also change their forms.

The growth of a cell-wall is rarely regular, so that a cell seldom retains its original shape, and in general, the growth is irregular, so that certain parts of the cell-wall expand more than others. The composition also of the cell-wall, is not homogeneous, and we find in it a striated appearance, due to alternate layers of more or less watery cellulose. This is termed *stratification*, when seen in section, and *striation* on the surface of the wall.

The size of full grown cells varies greatly, the diameter generally ranging from 0.004 millimetre to 0.8 millimetre.

Size of full grown cells.

The simple fibres or elongated cells of the following textile substances attain the lengths given below :—

Jute, ...	...	...	...	1.5 m.m.
Hemp, ...	...	...	...	40.0 "
Cotton, ...	...	...	...	50.0 "
Rhea, ...	...	...	...	250.0 "



The *pollen tube* of the colchicum may be 125 millimetres long.

Wood fibres in pines may be 0.025 millimetre in diameter, and 1 millimetre long.

The increased dimensions of a full grown cell as compared to those of its young state, may be due

Cell growth. to—

Apical growth.

Surface expansion.

Thickening.

Deposition of mineral matter.

When one portion of the surface of a cell grows much more than the rest of it, such growth is termed **Apical growth of cell-wall.** *apical*, as distinguished from *intercalary growth*, when the whole surface of the cell expands.

Root hairs afford a good example of this mode of growth. Apical growth instead of being confined to certain points in the surface of the cell-wall may take place along certain lines, giving rise to projections or ridges, as in many hairs, *stellate cells* and pollen grains.

Surface expansion is simply the intercalary growth which we have already explained, where a cell expands in size without much change in form.

Surface expansion.

A thickening of the cell-wall generally accompanies surface expansion, and may be *regular* or *irregular*.

Thickening of cell-walls. The former, however, is very rare, whilst the latter is common and generally *internal*, and gives rise to the markings seen in cell-walls, other than striation. An instance of *external* thickening is seen in the *cuticle* of the epidermis of plants.

The internal thickening of cell-walls is formed of materials, differing chemically from cellulose, and **Internal thickening of cell-walls.** which, unlike the primary membrane, do not become blue, under the influence of sulphuric acid and iodine. These thickenings are frequently composed of lignose. Woody fibrous tissue is largely formed of lignified cells, and serves as *conductive tissue*, to convey water from the soil to the crown of trees and shrubs.

The original cell-wall is termed the *primary membrane*, whilst



others formed inside it are termed *secondary* and *tertiary*. In cotton wool, the cell-walls are almost pure cellulose, without any lignified thickening.

Independently of the external thickenings already referred to, the appearance of cells from the same or different parts of the plant may differ, owing to—

- (i). The appearance of the thickened portions of the cell-wall.
- (ii). That of the unthickened portions.

The primary membrane is transparent, so that any markings beneath it are readily visible.

Under (i) we have—

Spiral thickenings.

Annular, or striped thickenings.

Reticulate thickenings.

Spiral cells have their secondary or tertiary membranes in the form of one or more (1 to 20) spiral threads, which in young cells can be readily unrolled from the primary cell-wall; these are termed *unrollable spirals*. The steepness or reverse of a spiral thread depends on the time at which it is formed: those formed, while the terminal shoot is growing rapidly, being the steeper. The growth of cells in some cases is so rapid that, the spiral thread is sometimes torn off the cell-wall. Unrollable spiral threads are very abundant in the leaves of the plantain (*Musa paradisiaca*).

Annular cells have their thickenings in rings, generally narrow and in parallel planes at regular intervals. They sometimes form discs slightly

perforated in the centre.

The spirals, as well as the rings or discs, serve to keep the cell distended, and prevent it from being pressed flat by the growth of surrounding cells. When the rings are very close together, the cells are termed *striped*.

Reticulate cells have their thickenings in lines which do not, as in the annular or striped cells, extend all round the cell-wall, but give it an irregular

ly striped appearance.

They are only found in older parts of plants, where increase in length has almost ceased; while spiral and annular cells are

found where extension is still going on. Spiral threads over 30 centimetres long have been found lining rows of cells, whose transverse membranes have been absorbed, as in a species of *Crinum*.

Cells of the second class may be—

Cells whose appearance is due to the unthickened portions of the cell-wall.	Dotted,
	Pitted,
	Scalariform.

Dotted cells have their inner membrane covering the larger part of the primary one, but with little gaps in it forming tubes (sometimes branching outwards) down to the primary membrane. It is generally found that in two adjacent cells these tubes are opposite to one another. When large they are termed *canals*, and they generally run from the cavity of the cell outwards, and are then closed by the thin primary membrane, which in many cases is absorbed, when the cell loses its protoplasm and dies. In this case, the canal between the two cells is open, as happens in many kinds of wood.

Pitted cells have funnel-shaped gaps in the thickening, and frequently the primary membrane appears to be completely absorbed, but has really expanded and become really attached to one of the sides of the cavity. Owing to the transparent primary membrane, the lens-shaped cavity formed in the midst of the walls of two adjacent cells with tubes leading to it on either side, resembles a pit with a circular border, and hence such cells are termed *bordered pitted cells*.

Pitted cells are largely found in the wood of coniferous trees, and in that of the yew (*Taxus baccata*), the secondary membrane is lined by a third membrane in the form of one or more spirals.

When the border and pit are greatly elongated and narrow, the cells are termed *scalariform*, and such cells are only found in the older portions of plants, specially in ferns and lycopods.

It sometimes happens that the thickening of the cell-wall only takes place at one side of the cell, which may continue to live and produce new cells. This happens in the case of the mistletoe (*Viscum album*).

Different forms of thickening on the same cell.



The markings on cell-walls are not always uniform, certain cells having one kind of marking below and another above. Thus a cell may be *spiral* above and *striped* below.

Quantities of mineral substances, such as silica, calcium carbonate, &c., sometimes crystalline and sometimes amorphous, are deposited either within the cell-wall or in the interior of

Deposition of ash constituents.

the cell cavity. In many cases, as in bamboos, large quantities of silica are deposited in the cell-wall. Amorphous masses of opaline silica, termed in Northern India, *tabdshir* or *banslochan*, are also found in the hollows and nodes of bamboos. Large quantities of calcium phosphate have been found in teak wood, and of calcium carbonate in khair (*Acacia Catechu*), and by the presence of lime, the quality of the cutch manufactured is largely improved.*

When mineral matter occurs in a crystalline form in plants, it is generally either calcium carbonate or oxalate, the former being extremely common in sea-weeds, and the latter throughout the Vegetable Kingdom.

When crystals are deposited in masses in the cell-cavity, they are termed *cystoliths*, commonly found beneath the epidermis in *Ficus elastica*, whilst long needle-shaped crystals are termed *raphides*, and are common in the bark of *Urticaceae* and many other plants, generally occurring in bundles.

Plants growing under favourable circumstances produce a much larger quantity of nutritive material than they can employ at once for the growth of cells. These materials are therefore stored up in the cells for later use, and may be termed *reserve material*.

Starch grains.

We have already referred to aleurone and crystalloids, as reserves of protoplasm forming material, for which the general term is *protein*. Another substance stored up in far larger quantities is termed *starch*.

Starch appears as solid grains having a concentrically stratified structure, which arise in contact with protoplasm, and continue to grow until separated from it.

Every starch grain consists of starch, water and a very small quantity of mineral matter. It has the same chemical composi-

* *Vide* a paper in "Indian Forester," Vol. XII., page 257.

tion as cellulose ($C_6 H_{10} O_5$). In each grain, however, there are two kinds of starch—

Granulose.

Farinose.

The former is easily soluble in water, and assumes a beautiful blue colour with iodine solution. Farinose is less easily soluble, and resembles cellulose in its reaction.

When the grains of starch are very closely packed within the cell, as in the endosperm of maize, they are polyhedral.

When water at $50^\circ C$. is added to starch, the granules burst and swell up into paste.

The striated appearance of starch grains is due to more or less watery layers, as in cell-walls. There may be one or more nuclei within a grain of starch, and growth takes place by intussusception, as in the cell-wall.

The shape of starch grains in different substances is characteristic, and may be detected by the microscope, and this is very useful to discover adulteration in food, &c., or in cases of poisoning to detect the kind of poison used.

Large quantities of starch are found in potatoes and other *tubers* and roots, such as those of *Manihot utilissima* and *Maranta arundinacea*, yielding tapioca and arrowroot, also in the stems of certain palms and cycads from which sago is extracted, in cereal grains, wheat, rice, &c., and these different forms of starch are largely used for food, and in manufactures.

When a mass of cells becomes united by the absorption of some of their common membranes, it is termed a
Cell-fusions. *cell-fusion.*

A common form of cell-fusion is found in wood vessels, which are elongated, cylindrical or prismatic rows of cells, the common partitions of which are more or less completely absorbed, leaving a hollow tube in the centre. They are only found in the higher plants, such as ferns and phanerogams, which are therefore termed *vascular plants*. They are of large size in the common cane (*Calamus Rotang*), and are readily seen in sections of most dicotyledonous woods.

The earlier the absorption of the partition takes place, the more complete it is. If, however, it occurs in older cells, *moniliform*



vessels are formed, in which the component cells can be distinguished, resembling beads in a rosary or necklace.

When the fusion takes place in very young cells, it frequently happens before any secondary membrane has lined their interior, and a continuous spiral may be afterwards formed inside a vessel.

Vessels may be distinguished by their appearance, due to their internal markings, in the same way as cells, and are thus spiral, annular, scalariform, &c.

Except in their walls, vessels only contain cell-sap at certain seasons when growth is vigorous, and the sap is forced into their cavities by its great pressure; it, however, only remains a short time within them, and they ordinarily only contain air.

Another instance of cell-fusion occurs in the case of *laticiferous ducts*, found in many plants, especially in figs, as the *Ficus elastica*, also in some *Compositæ*, as the lettuce, and in the families of *Apocynaceæ* and *Euphorbiaceæ*, of which respectively the Oleander (*Nerium Oleander*) and *Euphorbia Royleana* are examples.

These ducts contain a white milky fluid termed *latex*. They are frequently branching, and form a network like the veins of an animal, and are then said to *anastomose*.

Sieve tubes are found in the bark of vascular plants, where they occur as long tubes with thin walls and transverse partitions perforated by a number of pores, and termed *sieve-plates*. These plates are usually broader than the diameter of the tube.

The cavity is filled with nitrogenous matter, which passes from one tube to another through the pores of the sieve plates. Plates are also sometimes found in the sides of the tubes.

The length of the sieve tubes varies from 2 millimetres in the common cane to less than 0.01 millimetre in other plants, and the diameter attains 0.08 millimetre in species of *Cucurbita*.

The walls of sieve tubes are always formed of delicate, unligified, colourless cellulose, and owing to their delicate nature, it is very difficult to distinguish them, but by taking thin sections of the bark of a plant and adding iodine solution, the albuminous matter within the sieve tube is coloured brown. If then, we dis-



THE CELL, ITS NATURE.

solve away the walls by concentrated hydrogen sulphate, a moulding of them is obtained in their brown albuminous contents.

When a cell is destined to hold some peculiar substance, such as oil or resin, &c., it is termed a *gland*,

Glands. and a simple gland is formed from one single cell.

Compound glands are cell fusions, in which a number of adjacent cells coalesce to form a larger cavity, which afterwards may become filled with gum, resin, or some other substance. Such glands are common in the different species of *Citrus*, and contain the well known oil of lemons in small globular drops in the midst of a watery protoplasm. Compound glands are readily seen in the leaves of the common myrtle (*Myrtus communis*), and in those of most of the *Aurantaceæ*, the orange family.



CHAPTER II.

TISSUES.

WHEN a number of cells or cell-fusions are united together, they are said to form a *tissue*.

The thin wall between two young cells is simply the primary membrane common to them both. After **Intercellular spaces.** the cell wall has thickened, portions of the partition can be distinguished as belonging to either cell with the common primary cell-wall between them.

As a cell expands in size, it frequently happens that part of the primary membrane splits, as in rounded cells, where we find at their corners small triangular passages resulting from the rupture of their cell-walls, and generally filled with air. Such passages are termed *intercellular spaces*, and are very abundant in certain tissues, and communicate with one another, forming long air passages. Numerous air passages are found in the stem and leaves of the plantain.

In some tissues, the separation between the cell walls is complete, and they become a mass of isolated cells. This occurs in the flesh of many ripe fruits, pear, apricot, mango, &c., also in pollen grains. Isolation of cells may also be effected artificially by boiling, as in the case of mealy potatoes, where the primary cell-wall is partly dissolved, and the cells full of starch grains are liberated and rendered more soluble for the gastric juice.

Very large passages are sometimes formed in plants by the absorption of masses of tissue, after their primary cell-walls have separated. The hollow stems of lilies, bamboos and of *Umbelliferae*, and certain resin and gum passages, are due to this cause.

Young growing tissue, in which the cell growth is still in progress, or the cells are still capable of division, is termed *meristem*.

Meristem.

Certain elements retain during their life, the structure and all

the characteristic properties of typical cells, whilst others lose the cell nature. The former consist of a closed membrane, and contain living protoplasm and cell-sap, with generally a nucleus and other cell contents ; they retain the power of independent growth, and are still capable of division ; in consequence of this property, a meristem may again arise from them, even if they remain dormant for a time, and this is distinguished as *secondary meristem*. The latter lose with their development, the power of division and of independent growth, and are really dead cells.

Cells composing meristem are generally packed close together, without intercellular spaces, and with their polyhedral walls generally consisting merely of a primary membrane and their cavities still containing protoplasm.

In a dicotyledonous plant, the meristem found in its seeds, buds, and at the extremities of the roots, stem and branches, is termed *primary meristem* ; and it is by the sub-division and expansion of its cells, that all the various organs of the mature plant are eventually formed. After the full number of cells are formed in any member of a plant, they may expand considerably in size, without increasing in number, but tissue, where an increase in the number of cells is no longer possible, is not meristem.

If we consider the diagram of a dicotyledonous plant, we find first the small embryo, in the germinating seed, the whole of which, except the cotyledons, is composed of meristem.

The total number of cells is the same in certain parts of the mature plant as in the germinating seed, and this is generally the case with leaves, which contain their full number of cells in the bud, and merely expand in size after leaving it.

In some leaves, however, portions of the harder parts or nerves continue to be composed of meristem, even after the leaf has attained its full size, and such leaves under favourable circumstances, will produce complete plants, as in the case of different species of *Begonia* and in *Bryophyllum calycinum*.

As the seedling expands, a portion of the root ceases to have further power of producing new cells, or of expanding those already formed. Such a tissue composed of fully formed cells is termed a *permanent tissue*. In this case, the permanent tissue forms the *root cap* of the young plant. In the diagram, the per-



manent tissue is shown in white, the growing tissue is shaded in lines, and the meristem is colored black. *Procambium* is another name for primary meristem.

All the various members and organs found in a phanerogamous

The growing points plant spring from the growing point at either end of the caulicle of the embryo.

The stem, branches, foliage, flowers and fruit form the plumule, and the tap root and its branches form the radicle. An examination therefore of the growing point of both the plumule and radicle is important. If we make a longitudinal section through a growing point of the plumule of a phanerogamous plant, we find an outer layer of cells, which are very regular, and have their walls at right angles to the surface. This is termed the *dermatogen*, and from it the epidermis of the plant arises. In the centre of the section we find a tissue, termed the *plerome*, generally composed of elongated cells, and between it and the *dermatogen* an irregular cellular tissue, termed the *periblem*, from which the branches and leaves originate, and become covered with epidermis from the *dermatogen*.

As far as we know, the *plerome* of the parent shoot takes no part in the formation of a branch or leaf, but a new *plerome* is formed from the *periblem* of the latter.

The *plerome* eventually gives rise to the wood of the stem, enclosing *pith*, if one is formed, the pith being a soft cellular tissue, from which frequently a hollow tube originates, owing to the splitting asunder and absorption of its cells. The pith in the solar plant (*Æschynomone*) is of large dimensions.

The upward growth of a young shoot, is due to the continuous cell division of these three layers of meristem, and each is continued downwards in definite tissues, which we shall hereafter describe.

The *dermatogen* layer is always distinguishable from subjacent tissue, but the *plerome* and *periblem* are not always as sharply defined, as in our diagram.

In the case of roots, we find a layer of cells loosely joined together, and the outer ones separating from the general mass, and forming the *calyptra* or root cap, common in phanerogams, but absent in many plants growing in water.

If no pith is formed from the plerome, as is the case with many roots and some stems, the whole of it becomes converted into a *fibro-vascular* cylinder. The soft cellular tissue, outside the hard axial cylinder of roots arises from the periblem. These tissues are readily distinguishable in young roots.

In the lower plants, such as sea-weeds (*Algæ*), we find a single large cell at the growing point, termed the *apical cell*. It is from the repeated sub-division of this cell, that all the subsequent tissues of the plant are formed.

In the case of phanerogams, however, and the higher cryptogams, we find no such apical cell, but the primary meristem assumes the form we have given above.

At the *growing point* of plants, whilst the lower portions of the primary meristem are becoming changed into different kinds of tissue, primary meristem itself is renewed by the production of new cells close to the apex ; and in the case of the lower plants, a single new apical cell is constantly formed to replace the parent cell which has become divided into two. An exception occurs when the terminal shoot is converted into a flower and fruit, which eventually wither away. In this case upward growth ceases, but new meristem is contained in the seeds, if any are produced.

Plants which blossom at the terminal shoot are said to have a *definite inflorescence*, and such plants cease to grow in height when they flower. Trees with this characteristic, such as the teak, sal, &c., cannot attain the great height of others, as the deodar, pine, and oak with *axillary* or *lateral inflorescence* springing from the *axils* of their leaves, which are the points of junction of the latter with the stem and its branches, and not from the terminal shoot.

Regarding the height attained by certain trees, the deodar has been measured over 250 feet high on the Sutlej. 150 feet is the greatest height known for the teak, whilst *eucalypti* in Australia have been found exceeding 400 feet in height, and the *Sequoia gigantea* of California also exceeds 300 feet.

The following kinds of tissue are found in the epidermis or outer covering of plants, which immediately springs from the dermatogen—

Epidermal cells : stomata : hairs or trichomes.



Epidermal cells may form one or more layers, but most commonly the epidermis is only one cell thick. The general form of the epidermal cells may vary considerably, but the walls always fit closely together in adjacent cells, without other intercellular spaces than those of the *stomata*, which will be described further on. This close structure in the epidermal tissue, serves to protect the plant from the rain and other external agencies. The walls of the cells, though fitting closely, may be *wavy*, and are generally flat, with their least extension perpendicular to the surface of the epidermis.

This is termed their height, and the length and breadth of cells are considered to be the same in direction as those of the members to which they belong.

Several layers of cells are found in the epidermis of species of *Ficus*, the leaves of which are remarkable for their leathery nature. Also in the pepper family, in which as many as 16 layers of cells have been found in the leaves of one species, the epidermis being thicker than all the rest of the leaf put together. These several layers are produced by the sub-division of one original layer.

Between the cells of the epidermis, we find little pairs of cells distributed with concave sides, and a slit
Stomata. between them. This slit communicates

with an intercellular space below the epidermis, termed the *respiratory cavity*, and serves for the transpiration of air and watery vapour, from the interior of the plant into the atmosphere. The pair of cells with the slit, is termed a *stoma*, and the cells bordering the slit are termed *guard cells*. The guard cells differ from the surrounding epidermal cells in containing a mass of protoplasm, and in their smaller size; they also possess the power of contraction or expansion according to the moisture of the atmosphere, and intensity of light and heat. The slit becomes wider by the curvature of the guard cells, under the effects of light and heat, and closes when this light and heat are insufficient, by the consequent contraction of the guard cells.

As regards the size of stomata, the slit in certain lilies is .008 millimetre broad, and about six or seven times as long. But in most cases, it is very much smaller than this, and in fact, the stomata cannot be seen without a microscope, though sometimes when cer-

tain parts of the leaf contain very numerous stomata, its lighter colour there is readily noticeable. In the needles of the silver fir (*Abies Webbiana*) and several other conifers, we find two white lines, on the under surface of the leaf, which are due to a white resin filling up the slits in the very numerous stomata.

The *guard cells* of a stoma are formed by repeated sub-division of an ordinary epidermal cell, and are separated from one another by the splitting of their common cell-wall.

In some cases, the stomata are sunk in the epidermis, as in many tough skinned leaves, such as those of conifers, many monocotyledons, as the aloe and agave, and in different species of *Ficus*.

The stomata may also be level with the surface of the epidermis, or may be pressed by the surrounding epidermal cells above its outer surface, as in the oleander.

From many examples of the position of stomata, the conclusion is drawn that the depressed position is common for leathery, succulent and thick skinned parts, and the superficial position for more herbaceous plants, but this rule is not universal.

In a number of cases, we find neighbouring cells of the epidermis differing from others which do not touch the stomata, and very often resembling the *guard-cells* themselves. Such cells are termed *subsidiary*.

Stomata may be distinguished as *air-pores* and *water-pores*.

In *air-pores*, the slit is found filled with air and communicating with the respiratory cavity below, and the guard-cells are always capable of curva-

ture, so that the slit is variable in size. It is evident, therefore, that the stomata in the first case, allow the external air to pass into the plant, and also air and watery vapour from the plant to pass out into the atmosphere, when the plant is said to *transpire*.

Air-pores as well as *water-pores* are completely absent on roots, but may be found on every other part of the plant. They are most abundant on green leaves, but in certain plants without chlorophyll, as the *Lastræa*, they are almost entirely, or altogether, absent.

In underground stems and shoots, such as the tubers of the young potato before it is covered with cork, air-pores are abundant. Air-pores are also generally absent in submerged leaves, though



they have been found very exceptionally in a few cases. In amphibious plants, as the *Ranunculus aquatilis*, air-pores are, or are not found on the leaves, according as the latter are above or below the surface of the water.

Air-pores are only found on those parts of a plant which cover masses of tissue full of intercellular spaces. They do not occur, for instance, on the nerves of a leaf, which are without intercellular spaces, but are abundant in the cellular tissue between the nerves.

The number of air-pores varies widely in different parts of a plant; on the leaves of many monocotyledons, almost every epidermal cell bears a stoma, while in many woody plants, there is only one stoma to many hundred epidermal cells. In the cabbage, 716 stomata per square millimetre have been counted on the under surface of a leaf. On most foliage leaves, the number varies between 40 and 300 per square millimetre, whilst on stems of woody plants, the stomata may be several millimetres apart. In plants destitute of true leaves, as the *Casuarina*, species of *Cactus*, *Equisetum*, &c., the green branches are rich in stomata. On one *Cactus*, 18 stomata have been found on one square millimetre.

In the case of firm leathery leaves with a smooth shining upper surface, as silver firs, oleanders, hollies, rhododendrons and figs, the stomata are, as a rule, on the under surface of the leaf, and the lighter colour we frequently notice on the under surface of leaves is due to their underlying cellular tissue being full of intercellular spaces.

It is very rare that stomata are more abundant on the upper surface of leaves, though in certain grasses and in *Pinus Strobis* they only exist on the upper surface of the leaf.

Many flat leaves which stand vertically, have equally numerous stomata on both surfaces.

Leaves floating on water have stomata almost exclusively on their upper surface.

Many plants, besides their air-pores possess *water-pores*, from which drops of water, sometimes holding

Water-pores.

in solution calcium carbonate, may exude, in the latter case, the calcium dries at the orifice.

Water-pores differ from air-pores by the slit and cavity being at times filled with water instead of air, and by the guard cells being immovable. They are found at the ends of the nerves of the leaves, and therefore along the margins of the latter. Their size is frequently far greater than that of air-pores. In the case of poppies and arums, they are very large indeed. Many arums have leaves, with water-pores at their points, from which drops of water exude.

Out-growths above the outer surface of the epidermis, and which do not merely belong to the cuticle, are termed *trichomes*.

Mere projections of the cuticle are not trichomes, nor are structures resembling them, in which the subjacent tissue to the epidermis takes part, forcing its way upwards and still covered by the epidermis. Such structures, as in the prickles of roses, are termed *emergences*.

Trichomes are of the following kinds :—*Hairs, bristles, prickles, warts and scales*.

According to the abundance of the trichomes, which cover them, the various members of a plant are termed *pilose* when covered with soft and distinct hairs, or *pubescent* when the hairs are short and matted.

Hairs may be either unicellular or consist of a row of cells simple or branched. We may distinguish the body and the foot of each trichome, the foot lying within the epidermis, and the body lying beyond it.

A surface may have all its trichomes of the same kind, as in the case of root hairs, but more commonly, different kinds are found on the same surface, side by side.

If we disregard root hairs, which are almost universal in the higher plants, only a few families are distinguished by the absence of trichomes. These are the *Equisetæ*, *Coniferæ* and one or two others. The duck-weed family, *Lemnaceæ*, are entirely destitute of trichomes, even of root hairs.

Hence trichomes are almost universally found on some part or other of the majority of plants, though their actual quantity varies considerably.

Trees and shrubs with foliage pubescent on the under surface are common at high altitudes, and the foliage of the borass

(*Rhododendron arboreum*) and of the bán and the kharsu oaks of the Himalayas (*Quercus incana* and *semicarpifolia*), are peculiarly suited to withstand severe frosts, insolation, and drought, and may be compared with the delicate foliage of the moru oak (*Quercus dilatata*), which in young plants always requires protection from the effects of frost and of the sun.

Trichomes are even found on submerged species, as in the water lily, but generally we may say that hairiness increases with the degree of insolation, the dryness and airiness of the spot, for the same or allied species. Trichomes originate at a very early age on the stem or leaf on which they are formed, appearing even before the stomata.

We are all acquainted with the extreme hairiness of young leaves, even when contained in the bud, as compared with those fully formed. As the bud unfolds, the thickness of the hairy covering decreases, partly because the hairs become more distant, as the leaf expands, and partly because the hairs may be gradually removed from the unfolded parts.

Parts of plants that are entirely free from trichomes are termed *glabrous*.

When the hairy covering is only present on partially developed members, the surface is said to be *glabrescent*, as in the foliage of the loquat.

Hairs are thus said to be *transitory*, when they are only found on immature members, and *persistent* when the reverse is the case.

In roots, the root-hairs always appear on the portion which is just ceasing to extend. By this provision, the root-hairs are saved from being torn off, as the root increases in length.

Hairs on tender young buds tend to protect the growing point from changes of temperature. The growing point of the root is protected by the soil itself and is destitute of hairs.

Root-hairs are nearly always unicellular and unbranched. They cover the young roots and rootlets, except at their extremities, and fall off as the members which bear them become older. We shall afterwards see that they absorb moisture and mineral and nitrogenous matter from the soil for the nourishment of plants.

Under the term *tufted hairs* we find *stellate hairs*, as in the chestnut.

Capitate hairs have a disc-shaped head, and are generally glandular and contain some special substance such as resin, or volatile oil.

The stinging hairs of nettles and other plants secrete an acrid fluid, which, as their brittle points break off, enters the object touching them. Such hairs have *basal glands*.

The prickles of the cane are trichomes, and so are the scales which give a silvery appearance to the under surface of the foliage of *Elæagnus*.

The long hairs attached to cotton seeds and to those of the different species of *Bombax* are used for textile purposes, and for stuffing pillows, &c.

The structure of epidermal cells may be readily seen under the microscope in the epidermis of the agave.

Structure and contents of epidermal cells. They generally contain a delicate lining of protoplasm, and within it a clear transparent cell-sap, and the membrane of the cell-wall being transparent, the subjacent tissue can be readily perceived through it. The cell-sap in the epidermis is, however, sometimes coloured with erythrophyll, but, as a rule, the epidermal cells are colourless. Chlorophyll and starch are generally absent from epidermal cells, and this is always the case with land plants with a thick walled epidermis, whilst in that of the foliage of plants with delicate leaves and growing naturally in the shade, such as balsams, chlorophyll and starch are present, also in a few plants growing in sunny places. Plants growing in fresh water however, generally have their epidermis rich in chlorophyll.

As a contrast to the ordinary epidermal cells, the guard-cells of the stomata are very rich in protoplasm, chlorophyll and starch. In colourless plants, however, only starch is present in the protoplasm. The subsidiary cells of the stomata are intermediate between the epidermal and guard cells.

The young cells of trichomes are frequently full of protoplasm, whilst as they become matured, the protoplasm merely lines their cell-wall, except in the case of stinging hairs of nettles (*Urtica*), in which the protoplasm remains in considerable quantity. In other mature hairs, the protoplasm and cell-sap are dried up and replaced by air.

All root-hairs and many of the hairs on the foliage of plants



contain cell-sap, but no root-hairs contain chlorophyll. The presence of cell-sap renders these hairs transparent.

When certain parts of the leaf, such as the under surface, or even the stem, are covered with a number of dry hairs or scales containing air, these frequently appear as a dense white felt *tomentum*, formed over the part. This is the case with a herbaceous plant found in the Himalayas, (*Senecio densiflorus*), and its white felt is used as tinder by the hill people. A small Himalayan shrub (*Colquhounia*) has a similar tomentum.

The cell-walls of the epidermis are composed of cellulose, but a number of other substances are embedded in it, or superposed above it.

Composition of cell-walls of the epidermis.

Some of these are—

Cutin,

Wax,

Resins, { mixtures of resins and volatile oils are termed
 balsams.

Volatile oils,

Gums, mixtures of gums and resins are termed *gum-resins*.

Silica and calcium compounds.

In some epidermal cells, the pure cellulose is converted into mucilage, especially in strong leathery leaves.

Cutin occurs in the *cuticle* and is a non-nitrogenous compound, which may be dissolved by boiling in a solution of potash. It is also only slightly

Cutin.

affected by hydrogen sulphate, which would destroy the non-cuticular layers of the epidermis. It is coloured yellow by iodine preparation, with or without hydrogen sulphate. Its physical properties have been already described, and owing to its rendering the epidermis impermeable to water, it excludes moisture from without, and prevents the transpiration of internal watery vapour except through the stomata.

The cuticle covers the whole outer surface of the epidermis, including the hairs, as a thin closely applied transparent skin. It appears on the

Cuticle.

embryo, whilst the latter only contains a few cells, and continues till the epidermis is thrown off. It is absent at the covering point of the extremity of roots, but appears behind it. It covers the

orifice of stomata down to the respiratory cavity, becoming gradually thinner as it proceeds inwards. In *Cactaceae*, it covers the whole of the respiratory cavity.

It is very thin on submerged plants and roots, and thicker on sub-aerial parts.

In the thick walls of epidermal cells, the cellular membrane is permeated with cutin, which may extend over all the elements of the epidermis, then said to be *cuticularised*, as in the leaf of the *Ficus elastica*, and in the very hard epidermis of pine needles.

We frequently find that a wax-like substance, which in its solubility and fusibility under 100° C. resembles bees' wax, is found in connection with the cuticle and the cuticularised portion of the epidermal wall.

Wax.

All such substances are soluble in boiling alcohol, or in slightly warmed ether.

The wax is not, however, always pure, but may contain resin, which is soluble in cold alcohol.

Besides resin, it may also contain silica. Wax assists the cuticle in excluding atmospheric moisture from the subjacent tissues of a plant and in restraining transpiration; it is not found in submerged or underground parts. In sub-aerial members, however, it is almost universally found, and in the epidermis, partly embedded in the cell-wall and partly coating the cuticle, as in the leaves of the agave and the honeysuckle.

The imbedded wax is only found in the cuticular layers and not in the pure cellular membrane, and can be extracted by boiling alcohol.

Wax coverings are exuded by the cuticle in four different ways :—

Crusts.

Rod-like coverings.

Granular layers.

Aggregations.

The *crusts* give rise to a kind of clear brittle glaze, which sometimes appears broken up into angular pieces. This glaze may be very thin, as in species of *Thuja*, or we may have massive



wax layers, attaining a thickness of 5 millimetres, as in the wax palms of the Andes, *Ceroxylon* and *Klopstockia*.

A mature *Klopstockia* will yield 25 lbs. of wax, which is scraped off the stem. A composition of two parts resin, one part wax and one-third tallow, makes excellent candles.

In this palm, long orifices over the stomata are left in the wax.

In the second case, we find *rods of wax* perpendicular to the cuticle, which in the *Saccharum* (sugar-cane) attain a height of 15 millimetres, and also occur in bamboo culms.

In this case, the height of the wax covering is greatest on the internodes, forming a mealy covering which is easily brushed off.

The wax forms a *granular layer*, when the granules of wax are not heaped up, but simply placed side by side.

A granular layer one millimetre thick is found on the vine leaf, the granules being scattered. In the cabbage, they touch one another, and when not too far distant, form the white or blue easily removable *bloom* of plums and grapes.

Aggregated wax coverings of several layers are found in *Eucalyptus globulus* and the castor oil plant.

The wax on the cuticle of plants is not formed by degradation of the cell-wall itself, as gum, resin, mucilage, &c., which are termed *degradation products* of the cell-wall, but is really exuded by the cuticle.

In the cell-walls of the epidermis, we find glands containing resins, volatile oils or mixtures of both, and mixed with them also, though more rarely, vegetable mucilage (*Bassorin*), gum and sugar. They are termed *dermal glands*.

These substances sometimes give the surface a sticky character, as in a common species of *Clerodendron*. If volatile, they are perceived as scents, as in *Aloysia citriodora*.

Both the sensations of stickiness and odour may be combined.

These substances are said to be the *secretions* of the glands which contain them, but contrasting with the general appearance of the wax all over the epidermis, they are usually found localized and most commonly in trichomes, as in *capitate* and other glandular



hairs and scales. We may take *Pogostemon Patchouli*, a strongly scented *Labiata* plant, as an example of a plant yielding a volatile oil contained in glandular hairs.

The *Labiata* family is noted for its volatile oils, as in mint, sage, lavender, rosemary, thyme, and basil.

The glands on the floral leaf of the hop consist of scales containing a bitter matter used in brewing.

The stickiness of the surface of certain plants is only perceived when the glands have burst, and their contents is not simply a volatile oil.

Certain ferns, such as the silver and gold ferns, and many primulas, owe their dusty covering to capitate hairs, which excrete small granules of resin in the form of a mealy dust.

Hairs containing mealy dust.

las, owe their dusty covering to capitate hairs, which excrete small granules of

In certain plants, which do not assimilate sufficient nitrogen in any other way owing to their growing in swamps, or to some other cause, as

Digestive glands.

Drosera, *Dionæa* and *Pinguicula*, we find hair-like dermal glands secreting a fluid, holding in solution an organic acid and a ferment resembling pepsine.

These two substances are capable of dissolving nitrogenous substances from insects, and from minute fish in the case of *Utricularia*, which they secure by means of certain mechanical arrangements we shall describe further on. The nitrogenous matter procured from these bodies is then absorbed by the surrounding tissue of the plants.

Such plants are termed *carnivorous*.

Silicification of the epidermis, and especially of its cuticularized wall, is common, and highly silicified

Silicification of the epidermis.

epidermal layers are hard and firm, as in—

Equisetum, *Calamus*, grasses, fronds of ferns, &c.

In the stinging hairs of nettles, the upper brittle part of the wall is strongly silicified, the lower part but little, so that the hard points breaks off, and allows the acrid glandular contents to flow into the wound.

It does not follow, however, that all hard leaves are silicified, for the epidermis of the leaves of palms, pines, cycads, &c., do not



owe their hardness to this cause, but to cuticularization of their tissues.

Calcium oxalate is found in the epidermis, either in crystals or in granules, in species of cypress, *Dracæna* and the yew.

It has never been found in sea-weeds, mosses or vascular cryptogams, but occurs in fungi and lichens.

Calcium carbonate is found in many hairs, and especially in the cystoliths of figs and other allied plants.

Calcium carbonate is often found incrustated on the outer surface of the cuticle, as in many ferns and saxifrages, also in certain water plants in which the whole epidermis is covered with a thick layer of calcium carbonate.

Calcium carbonate is also common in many sea-weeds.

Cork or periderm is found in mature plants as a tissue with all the physical properties of cuticularized epidermis, the place of which it supplies, when the latter is thrown off with the advancing age of the plant, or when the subjacent tissues are exposed by wounds.

A familiar example of a wounded surface occurs, when a potato is cut and planted, each of the exposed surfaces rapidly becoming covered with a layer of cork.

Exceptionally, cork appears as a strengthening of the persistent epidermis.

All known phanerogams are capable of forming cork ; cryptogams, only in isolated cases.

Cork formation always originates in the epidermis or in living cellular tissues below it. Wound surfaces are healed by it, and diseased or dead parts are isolated from those still living, as in the case of stool shoots from a coppiced tree, or in the separation of members thrown off, such as leaves, the scars of which may be placed amongst wound surfaces.

Cork appears on the stems of most dicotyledons, gymnosperms, and a few monocotyledons which have a long continued growth in thickness. It is less generally present on the long lived, but not continuously thickening stems and shoots of monocotyledons, most of which retain their epidermis.

Finally, in rare cases, cork is formed on the surface of certain leaves, as in the winter buds of the horse-chestnuts, poplar, elm, and spruce, which it assists in protecting from the effects of frost.

Cork formation begins with a single layer of cells parallel to the surface which is to be shut off, by divisions also parallel to that surface.

This initial layer of cells giving rise to a zone of cork may be the epidermis itself in certain cases, but is generally beneath it, and is a form of meristem known as *phellogen*.

By repeated sub-division of the *phellogen*, new layers of cork cells are formed outside and a new layer of *phellogen* inside, until, at last, the layer of cork may contain from two to twenty layers of cells.

In certain special cases, as in the cork-oaks (*Quercus Suber* and *occidentalis*) and in *Testudinaria*, a genus of the order of yams (*Dioscoreaceae*) from South Africa, the external layers of cork are of considerable thickness.

As examples of Indian plants with external cork, we may take the *Erythrina suberosa*, *Excoecaria insignis*, and the box (*Buxus sempervirens*).

Cork-cells are uninterruptedly connected with one another, there being no intercellular spaces between them, except in one family, the *Melastomaceae*; the cells are also generally brick shaped, or prismatic, and more or less flattened.

The cells of the *phellogen* form layers of similar cork cells placed one above another, which in a transverse section resemble a wall of bricks.

From a consideration of the structure of cork layers and their physical nature, cork being impervious to moisture, it is evident that, all passage of decaying matter from a wound to the healthy interior of a plant is prevented, as well as the passage of nutritive sap to the dying external portions, where it would only be wasted. These, therefore, speedily die, and are thrown off from the living plant. Leaves of dicotyledonous plants are thus cut off from the stem by a layer of cork at the base of the petiole, the section giving rise to a characteristic *leaf-scar* for each species.

In layers of cork, we distinguish cells with thin walls from

thick-walled cells. The mass of cells in common cork is of the former character, and in it, we notice thinner layers of darker cork forming concentric zones corresponding to the number of years during which the cork has been formed on the tree, the darker layers being thick-walled, and the outermost zone the oldest.

Cork cells have a primary membrane of cellulose, the cork substance forming the secondary thickening of the cell.

As regards colour, in the birch and certain willows, cork is colourless; in some palms, it is greenish-yellow. In other cases, it is bright brown, though generally the colour is light.

The young cork cell is lined with protoplasm and contains cell-sap, and a cork layer may remain transparent even when completely developed, so that the chlorophyll of the tissues below may be seen through it, as in the camphor tree (*Camphora officinarum*).

This transparent condition only lasts, at most, for a year, when the contents dry up and the membrane becomes filled with air, and sinks into gradual decay. Besides the cork cells, we find much harder cells in the bark of trees resembling the stone cells of pears, or peach stones, and composed of glukodrupose.

In the cork oak of commerce, such stone cells depreciate the value of the cork, and are sometimes found near the *lenticels*, which will be described further on.

The successive layers of cork may be either of uniform texture, or may vary in texture and hardness, the harder layer succeeding to a softer one. In the former case, the cork consists of more or less flattened cells, which cover wounds, and are evidently required to persist for a considerable time to give strength to the newly formed tissues.

The softer cells occur in the corky covering of trees in which such strength is not required, and these readily yield to the expansion of the stem. We may note here the long cracks formed in sál, and other saplings, with a tough thick bark.

It is the alternation of the thick and thin-walled cork layers which mark the annual zones in cork, and also allow the *laminæ* of bhojpatra bark to peel off the tree. The whitish colour of the bark of *Betula Bhojpatra* and *alba* is due to the air contained in the transparent cork cells.

TISSUES.

All internal cellular tissue, in which the cells are still alive, is termed *parenchyma*.

The presence of protoplasm is essential to living cells, but it is frequently very difficult to detect protoplasm in thick-walled and still living cells. We know, however, that starch appears and disappears only from living cells, and the presence of starch is easily detected by iodine solution. Hence, this property is a criterion of the fact that the cells form parenchyma, or not. As an illustration, we shall hear further on that, in the *sap-wood* of woody plants starch accumulates in the non-growing season, but leaves it in a large measure when vegetation re-commences. Hence, the cellular tissue of the sap-wood is parenchyma.

Although the presence of starch in dead cells is exceedingly rare, still it has been occasionally noticed, but it is then permanently stored in the cells, in a minute unvarying quantity, whilst in living cells, the quantity of contained starch varies from time to time.

The form of cells in parenchyma may vary in every possible way, and so may the thickening of their walls, but we may distinguish two forms—

Short cells, (*iso-diametric*):

Elongated cells.

We may also distinguish—

Thin-walled cells:

Thick-walled cells.

Thin-walled parenchyma is the seat of the processes of assimilation, such as chlorophyll—starch—and oil-cells, where a large cavity is necessary to contain the nutritive substance. This kind of parenchyma is found in leaves, in the inner bark, and in some roots and *rhizomes*, or underground stems, as well as in many succulent stems, as in the papaya. This thin-walled parenchyma is therefore characterized by containing reserve material for the future use of the plant. Another kind of parenchyma is also common, in which the cavities of the cells are full of sap. This forms the *aqueous tissue* found in thick foliage plants, such as the agave, also in large masses of tissue rich in sugar, as in the beetroot and the Jerusalem artichoke. Such



tissues are largely composed of water, which is more than half their weight. In certain aloes, mucilage is also found in the cell-cavities.

These thin-walled cells are generally short, but in certain cases are elongated, as in the *palisade tissue* found below the epidermis of the upper surface of many leaves, which contains chlorophyll, the dark green colour of the upper surface of the leaves, as compared with the lighter lower surface, being due to the thick layer of chlorophyll cells in the former.

The cells found in parenchyma are generally marked with ordinary *pits* and described as *dotted* cells, and the fact that, in neighbouring cells the perforations through the thickening membranes are opposite to one another, materially assists in the diffusion of reserve material, when it has become soluble.

In some cases, these tubes form sieves, but differing, however, from the sieve plates described before. Occasionally, reticulate and spiral fibres are found lining the thin cells of the parenchyma, as in the roots of orchids.

A certain form of thick-walled parenchyma is termed *collenchyma*, this forms thick bands near the epidermis in the stems of many herbaceous dicotyledons, as in the hemp (*Cannabis*).

The cells in collenchyma have only, exceptionally, intercellular spaces; they are polyhedral, thin at the middle of their surfaces, but thickened considerably at the angles, where several cells join; they contain chlorophyll grains.

The thickening material is composed of mucilage, and it is the presence of such layers of collenchyma in the elder (*Sambucus*), for example, which affords a gummy substance used in Europe for bird lime.

Other forms of thick walled cells are termed *Sclerotic*. Such cells are found within the wood of dicotyledonous trees in tissues which lay up starch, and which in spite of the thickness of their walls, are still capable of division, after being wounded.

Another kind of tissue is termed *Endodermis*, and forms protec-

five sheaths round certain internal membranes or cavities. These sheaths always consist of one layer of cells, and separate a mass of tissue from another mass of a different kind ; for instance, the fibrous inner cylinder of young roots is separated from their soft outer tissue by a sheath of this nature. The cell walls of these sheaths contain protoplasm, starch, and sometimes chlorophyll, and are frequently suberised. We shall see further on that, an endodermis, termed the starch ring, surrounds the primary vascular bundles of the stem of most dicotyledons, and the separate bundles in ferns, and occurs in the leaves of grasses and other plants.

Endodermis.

Tissue elements, which have not only thickened their walls at the expense of the cell cavity, but have also lost the cell quantity, and are in fact dead cells, are termed *Sclerenchyma*; together with the sclerotic cells already referred to, but which may take a share in nutrition, they assist in forming the strengthening apparatus of plants.

Sclerenchyma.

As regards the contents of these sclerenchymatous cells, we have already seen that, as their walls become thickened and lignified, the protoplasm and nucleus disappear almost completely, leaving aqueous matter, or air, in the cavity, together with certain indefinite granular contents.

Occasionally, sclerenchyma contains fine grained starch, which is however of no further use to the plant. At other times, it contains crystals of calcium oxalate, and frequently, the fluid contents are partially replaced by air. The walls of these cells are generally strongly thickened in various ways. They may be distinguished, as *short*, and *elongated* elements.

Among the short elements, we find *stone cells*, which resemble the sclerotic cells already referred to. They are found in the flesh of pears, and in many fleshy tuberous roots, in groups or masses, and especially in the bark of ligneous dicotyledons ; they are rare in monocotyledons, and do not occur in cryptogams.

Elongated *sclerenchymatous fibres* are spindle-shaped, with sharp

Sclerenchymatous fibres.

ends either simple or branched, and form a kind of strengthening tissue very common in phanerogams. They are sometimes found united into bundles

and layers, their ends passing between one another, like the teeth of two combs, or the fingers of two folded hands.

At other times, they are found singly, embedded in other tissues. The general name of *bast fibres* may be applied to them, derived from the term Russian bast, the technical name of the fibres of the lime, or linden tree (*Tilia europæa*).

As bast fibres are almost invariably found in the inner bark of plants, this inner bark has been termed the *bast*, but since the fibres are also found in other parts, as for instance in the leaves of the American aloe (*Agave americana*), and in New Zealand flax (*Phormium tenax*), it is better to confine the word *bast* to the fibres, wherever they may be found, and to term the inner bark of a tree, the *liber* or *phloem*.

When these fibres are closely united in bundles, their transverse section is polygonal, but those on the outside of the bundle adjoining softer tissue may be more or less rounded.

When the fibres lie singly, as in many leaves, their section is round. Those united in bundles are generally simple, unbranched, and tapering gradually towards the ends; those very elongated have their ends drawn out to extremely fine points.

Isolated fibres are frequently branched, the branches being usually of insignificant size.

Occasionally, fibres, much branched, are found in phanerogams. They are usually met with in spongy tissue, as in water lilies (*Nymphæaceæ*), the branches projecting into the interstices of the tissues.

The relation between the length and diameter of fibres varies

Dimensions of greatly in the same or different members of plants.

fibres. In very short fibres, such as those of Peruvian bark or cinchona, the ratio between their length and breadth varies between 10 and 20 : 1.

In *Urticaceæ*, yielding rhea and many other textile fibres, we find this ratio sometimes 4000 : 1.

The branched fibres are generally short, though this is not a universal rule.

The following figures for certain fibres are useful for reference :—

		Length, m.m.	Diameter, m.m.
Cinchona sp.,	...	0.875—1.25	0.03 —0.25
Jute (<i>Corchorus capsularis</i>),	...	0.8 —4.1	0.09 —0.015
Flax (<i>Linum usitatissimum</i>),	...	2.0 —3.0	0.15 —0.17
New Zealand flax (<i>Phormium tenax</i>),	...	2.7 —5.65	0.09 —0.13
Hemp (<i>Cannabis sativa</i>),	...	10 and more	0.15 —0.28
Rhea (<i>Bahmeria nivea</i>),	...	up to 250	0.04 —0.08

As regards the strength of different fibres, the rhea, from which Chinese grass cloth is made, when dry, may be broken with 240 lbs., and wet with 278 lbs., while the murruah (*Marsdenia tenacissima*) only broke with 248 lbs. dry and 343 lbs. wet. This fibre is used for fishing lines in Dehra Dún, and for bow-strings in the Rájmahal hills.

We must not suppose that all *textile fibres* are true bast fibres. In the case of cotton, hairs attached to the seed are utilized. In cocoanut fibre, we shall find later on that *fibro-vascular bundles* are used, as also in the fibres taken from the leaves of many monocotyledonous plants, such as the aloe and agave, in which only a portion of the fibres used in manufactures are real *bast fibres*.

The great length of certain fibres has made it supposed that some of them are cell fusions, but this is now considered erroneous.

The thickening of bast fibres varies, but usually all but closes the cavity of the fibre. It need not be of the same thickness all round, and this is the case in *Apocynaceæ*, and in jute fibres belonging to *Tiliaceæ*.

In certain cases, the thickening is continuous and without pits, as in most fibres used in manufactures.

In other cases, we find narrow pit canals, as in the fibres found in the bracken fern (*Pteris aquilina*).

In many fibres, numerous crystals of calcium oxalate are imbedded in their walls, as in *Welwitschia*.

Lignification of the Bast fibres may be lignified in a very wall of fibres. variable degree.

Of textile bast fibres, those of flax, hemp, and *Hibiscus cannabinus* turn blue of various shades with iodine and hydrogen sulphate, showing that they are composed chiefly of cellulose.

The fibres of jute and some other plants turn yellow or brown with the same preparation, as they are lignified. In ferns, the fibres turn dark brown.



The presence of lignose in a fibre renders it brittle and absorptive of moisture, and is consequently a disadvantage for textile purposes. Hence, fibres which turn yellow with iodine and hydrogen sulphate are inferior, in this respect, to those which turn blue.

Thus, jute fibres are inferior to those of flax and hemp on account of their lignified walls, and to those of rhea in length and strength, so that the great consumption of jute in manufactures is really due to its large and easy production in Bengal, rather than to its intrinsic good quality.

For the manufacture of paper, short thick fibres, which can readily be bleached and form a matted pulp when macerated in water, are preferable, and those of the paper mulberry (*Broussonetia papyrifera*) are excellent for this purpose. Those of *Daphne papyracea* are used for paper in Nipál.

In certain bast fibres, the thick inner layer is mucilagenous, as in the mulberry (*Morus alba*) and in *Celtis australis*.

It may also happen that bast fibres are formed by the lignification of collenchyma, in which case, the outer walls of the fibres still remain mucilagenous.

Contents of fibres.

Speaking generally, the contents of bast fibres have been already given under the head of sclerenchyma.

It has been found, however, that many fibres with larger cavities have contents resembling *latex*, which will be described later on.

In the majority of cases, the cavity in the fibres is a continuous hollow, very narrow, and ceasing far from the pointed ends. Chambered fibres have been found in the roots of palms, and in the bark of elms, which also contain starch for a time, showing how slowly the cell nature disappears.

Substances similar to the secretions of dermal glands, such as mucilage, gum, resins, volatile oils, and mixtures of these substances, termed *balsams*, as well as milky emulsions of both gum and resin, which in the dry state are known as *gum-resins*, occur in certain sacs formed from definite cells. These reservoirs, after attaining their full size, become completely filled with the substances in question.

These substances may also be found in certain intercellular spaces, and in the interior of wood fibres and vessels, as will be explain-

ed further on. Many of these sacs contain crystals of calcium oxalate as well as mucilage, and this calcium oxalate has been found to be of no further use to the plant, but to be merely a *waste product*.

The same may be said of all the other substances just mentioned, which unlike aleurone and starch, cannot be converted into food for the growing tissues of the plant.

These substances are also termed secretions, and the sacs, or internal glands, and intercellular spaces containing them—*secretory reservoirs*.

The distinction in the same plant between sacs and intercellular spaces is not always very clear, since rows or groups of cells by absorption of their walls may coalesce to form an intercellular space.

It is a rule that, plants with laticiferous tubes have no *internal glands*. Amongst the *Compositæ*, for instance, the family (*Cichoraceæ*) to which the lettuce belongs, has an abundance of latex, but no internal glands, whilst most of this natural order is distinguished by the presence of such glands, to which its aromatic properties are due, as in the common marygold.

It is also found, as a rule, that, plants with numerous dermal glands, as the *Labiata*, have no internal glands, whilst in *Umbellifera*, *Conifera*, *Aurantiaceæ*, *Myrtaceæ* and *Lauraceæ*, internal glands are abundant, and dermal glands are absent or rare.

Certain exceptions occur, as some of the *Compositæ*, have glandular hairs and internal glands.

In other cases, both forms are absent, as in most grasses, except the different kinds of lemon grass, in many *Crucifera*, and in *Taxus* alone, among the *Conifera*.

It has already been stated that, crystals of calcium oxalate are commonly found in cells, the commonest

Sacs containing crystals. form of the crystals being raphides, and sacs containing these are common in many species of aloe and cinchona, &c.

They are sometimes very long, even exceeding 5 millimetres.

The dried stem of the cactus (*Cereus senilis*), is found to contain more than 85 per cent. of calcium oxalate.

These crystal sacs occur in most plant families, and throughout all their genera and species. When the sacs are absent, as in species

of *Cupressus* and the yew, the calcium oxalate is deposited in their parenchyma, in the form of small crystals.

As a rule, no oxalate of lime is found in ferns or grasses, and it never occurs in *Equisetaceæ*.

When vegetable mucilage and other gummy bodies occur in parenchyma, they completely fill the cavity of certain sacs, commonly found in *Malvaceæ* (*Hibiscus*), *Tiliaceæ* (jute), and *Sterculiaceæ*. These sacs are distinguished from the surrounding parenchyma by their great size, and are either found singly, or else in groups, or rows.

Resin and gum resin sacs also generally contain a volatile oil, as in the case of the spirits of turpentine in which pine resin is dissolved. These sacs will be described more fully, further on.

Up to the present time, it has not been decided, whether or not tannin may be considered as a reserve, or waste material.

It is found, as various compounds of C H and O, in large quantities in many plants. They form insoluble compounds with animal gelatin, the chief substance of the skins of animals which by tanning are converted into leather.

They also form ink when acted on by iron salts, and gallic acid ($C_7H_6O_5$) and glucose, ($C_6H_{12}O_6$) with water. The glucose is detected in the sweet taste succeeding the first astringent flavor, as on eating fruits of *Phyllanthus Emblica*.

Tannin is soluble in water, and its presence may be readily detected in any bark by applying a small piece of ferrous sulphate ($Fe SO_4$) to the wet bark of the tree, when the intensity of the black stain will give an idea of the quantity of tannin in the bark.

If certain leaves, such as those of the common pear, be dried, they become black, owing to the tannin they contain. When bark is to be used for tanning, it is necessary to keep it dry, as the rain would wash out the soluble tannin.

Tannin is found in the epidermis, also in the starch-bearing parenchyma of many plants, as well as in the bark, wood, and in certain internal glands.

We will, however, only call those sacs which contain tannin and which do not contain starch as well, *tannin sacs*.



Such sacs are very common in *Leguminosæ* and *Rosaceæ*, as in the pods of the babul (*Acacia arabica*), the divi divi (*Cæsalpinia Coriaria*), tangedu (*Cassia auriculata*), and in pears and apples. Also, in *Combretaceæ*, which yield the myrabolans of commerce, the fruits of *Terminalia Chebula*, *belerica*, and *citrina*, and in the gall-nuts of oak leaves, which result from injuries by insects and are principally produced by *Quercus Cerris* on the eastern coasts of the Mediterranean. Extracts, such as *cutch*, made from the heart-wood of *Acacia Catechu* are rich in tannin, and a similar extract has been made from *sál* wood.

CHAPTER III.

TRACHEÆ.

TISSUE elements having the following characters are termed **Tracheæ**. *tracheæ* :—

(i). Walls become gradually thickened and lignified to a variable extent.

The thickening being—

(a). Fibrous (spiral, annular, &c.)

(b). Dotted or pitted.

(c). With transverse bars.

(ii). Almost simultaneously with the thickening, the whole of the protoplasm, as well as the reserve material of the cells in process of transformation, disappears completely, the cavity remaining filled with air or watery fluid.

There are two kinds of tracheæ—

Simple wood fibres, or *tracheides*.

Vessels, which are cell-fusions of rows of cells or fibres, and are frequently of larger diameter than tracheides.

Tracheæ are most commonly found in wood, but may also occur in parenchyma, and form a woody sheath around the sub-aerial roots of orchids, and thus assist them in absorbing moisture from the atmosphere, in the absence of root hairs.

As regards the thickenings of the walls of tracheæ, we have already described it under the head of cells, and the different kinds of thickening are occasionally found in living cells, though more frequently in dead ones.

One case of wall-thickening produces a growth of the membrane into the cavity in bars which may stretch transversely across it.

Tracheæ with transverse bars.

TRACHEÆ.

These bars are found in different species of club-moss (*Lycopodium*), and in junipers.

Dimensions of tracheæ.

Vessels may equal in length that of the whole plant in which they are found.

Their width is extremely unequal, and vessels with the greatest width are found in the vascular bundles of palm stems, especially in the common cane, where they may attain a diameter of more than half a millimetre, as also in the wood of certain climbers, and in that of the semal (*Bombax malabaricum*).

Vessels of greatest width are generally pitted.

From the nature of a vessel, which however long it may be, has always closed ends, it is evident that the diameter will vary at different points.

As regards tracheides or wood fibres, they may be short as compared with their breadth in a few cases, but as a rule they are elongated fibrous cells, with round, or polygonal sections.

They usually remain short, reaching from 0.16 to 1 millimetre in the wood of most dicotyledonous plants, but attaining 4 millimetres in some pine woods.

Most of the tracheæ are tracheides, and not vessels, which are not found in the secondary wood of *Coniferae*, are very rare in ferns, and only occur in some monocotyledons. We shall see later on that, the tubes found in coniferous wood are resin-ducts and not vessels.

Vessels may be formed from members of which the length is greater or less than the breadth.

Spiral or annular vessels which grow in length as the part elongates, come under the first head, whilst other vessels formed after extension is completed are composed of short members, as in the pitted and reticulated vessels of the vine, &c.

All tracheæ are alike, in that when fully formed, the protoplasm disappears entirely as in bast fibres, without leaving any vestige behind; the cell-walls alone remain, while the cavity of mature tubes contain a watery fluid, or air, or both; generally, only air.

In certain plants containing latex, resin, or tannin, the vessels frequently are filled with latex, or with one of the other substances. In old layers of wood of *Coniferae* and of many dicotyledons, such as, the sál (*Shorea robusta*) and pyinkado (*Xylia dolabriformis*), the

tracheæ are found filled with resin. This is a phenomenon of incipient degradation.

In old or damaged large tabular tracheæ, the cavity is sometimes filled with parenchymatous cells termed *thyloses*.

This may occur where a tracheide is bordered by parenchymatous cells, which protrude into its cavity through a pit or damaged portion of its walls, and by repeated sub-division, gradually fill it up entirely. This happens in the vine, when the vessels are several years old.

The cellulose wall of the thyloses becomes thickened, and starch is frequently stored up in their cavities. They are common in palms, in *Cucurbita*, the vine, and many other plants.

Many plants belonging to certain families contain, in tubes of definite structure, a milky opaque fluid, termed *latex*, from which the tubes themselves are termed *laticiferous tubes*.

These tubes traverse the parts continuously for long distances, adjoining the softer parenchymatous elements, and are not found in the harder parts of the plant.

They are completely filled with latex, and their walls, though often thickened, are soft and easily compressed, and at the slightest injury to the tubes, the latex exudes.

The wall of laticiferous or milk tubes is composed of cellulose. Protoplasm has not been found inside these tubes.

Latex is primarily a transparent fluid, in which numerous small bodies are suspended, forming an emulsion.

These bodies in most cases are colourless, as well as the fluid, and the milk is white, but occasionally orange-red or yellow, as in species of *Garcinia* yielding gamboge. The watery fluid, besides holding these bodies in suspension, has numerous other substances in solution, such as gums, sugars, albumen, tannin and other bodies, as morphin in the latex of poppy heads, which when dried becomes *opium*.

As soon as latex comes in contact with the air, and also after being treated with water, alcohol or acids, coagula appear in the fluid itself, independently of the insoluble bodies.

The suspended bodies vary in quantity, and the milk is the denser in proportion to their number. Thus the milk of *Nerium* and

Morus is only slightly cloudy, whilst that of *Ficus* and *Euphorbia* is dense and white.

The granules are in most cases immeasurably small. They are soft and sticky, and readily adhere together after leaving the plant.

As regards their chemical nature, they are generally resins or caoutchouc. Small quantities of fat and wax are also found, and in opium, certain alkaloids.

Caoutchouc forms a large majority of the insoluble granules in certain plants belonging to the following families :—

Apocynaceæ—

Urceola of the E. Archipelago, Landolphia, Vahea, of Madagascar and W. Africa.

Euphorbiaceæ—

Siphonia elastica, Manihot Glaziovii (the Ceara rubber), both of Brazil.

Urticaceæ, Artocarpeæ—

Ficus elastica, Hevea braziliensis, Castilloa, of Mexico.

Ficus elastica, a native of Assam, North and East Bengal, Bhutan, Upper Burma, Indo-China and also of North Australia, yields caoutchouc somewhat inferior to Para rubber, from the Hevea of the Amazon valley, but capable of great improvement when carefully collected.

The *Brosimum Galactodendron* yields a milk said to be as pleasant to the taste as that of the cow; it is found in Venezuela.

The latex of many plants contains highly poisonous alkaloids, especially in *Apocynaceæ* and *Euphorbiaceæ*.

We find the following composition of the latex of *Hevea braziliensis* :—

				Parts.
Water,	...	...	...	56·3
Caoutchouc,	...	...	...	31·7
Albumen,	...	...	...	1·9
Bitter substance, with wax,	...	...	...	7·1
Soluble substances,	...	...	...	2·9
Total,				99·9



Milk tubes may be either *articulated* or *non-articulated*. The former are found in the *Cichoraceæ*, a sub-order of *Compositæ*, including the lettuce, in many *Papaveraceæ* (poppies) and in *Papayaceæ* (*Carica Papaya*).

Non-articulated cells are found in—

Euphorbiaceæ,

Urticaceæ, (including *Artocarpeæ*), and

Apocynaceæ.

All milk tubes, whether articulated or not, traverse the whole length of the plant, sending branches into all its lateral appendages.

They have soft, smooth, or pitted cellulose walls, which thicken with age, but do not become lignified.

The articulated milk tubes are formed by the absorption in all directions of the walls of adjoining cells, and anastomose like the veins of an animal, forming a net-work throughout the plant.

Owing to the fact that, the milk tubes permeate the whole of a plant, it is possible to obtain large quantities of caoutchouc at a single tapping. As an example* of the quantity of caoutchouc, 50 trees of *Ficus elastica* were tapped in Assam in 1885, and each tree yielded about 5 lbs. of dry caoutchouc. The flowing of latex from a wound soon ceases, owing to the coagulation which takes place when it is exposed to the atmosphere. Gutta-percha is the dried latex containing resin from *Isonandra Gutta*, belonging to the *Combretaceæ*.

The non-articulated milk tubes do not form a net-work, as in the former case, but though they branch out freely, each of their branches ends blindly. Each tube arises from a single cell of the meristem, which continues to grow into a long branched sac, forcing its branches between the other tissue elements.

These tubes are instances of the apical growth of cells, which may attain the full length of the plant in which they are found.

Intercellular spaces are either formed by separation of the walls of permanent tissue elements owing to unequal growth, or by disorganization, dissolving, or rupture of certain transitory cells surrounded by permanent tissues.

* Vide "Indian Forester," Vol. XI., pages 260-61.



TRACHEÆ.

Intercellular spaces may also be distinguished according to their contents, being either *intercellular air*, or *water, reservoirs*, or *inter-cellular secretory reservoirs*, such as the resin ducts of conifers.

Air and water reservoirs are almost always found in large masses

Air and water re- of thin-walled parenchyma. It is evident
servoirs. that, reserve material, such as starch, could not be utilized by the plant unless it became soluble, and without the oxygen of the air, this would be impossible. Other reasons for the necessity for air spaces in parenchyma will be given under Physiology.

Such spaces are absent only from parenchyma, when it forms definite sheaths, and they extend between all cells, forming a continuous system throughout the plant communicating with the stomata, when they are present.

The spaces when near the water-pores, sometimes contain water, elsewhere, they normally contain air, *i.e.*, a mixture of gases similar to atmospheric air,* but in which the proportion of oxygen and carbon dioxide vary with the processes of assimilation and respiration.

The whole volume of the air spaces varies greatly, and is often very large in proportion to the solid parts of a plant, or that part containing aqueous matter.

Experiments have given from 77 parts of air by volume in 1,000 parts of other tissue, in camphor leaves, and 713 parts per 1,000 in the *Pistia Stratiotes*, a water plant common in tanks.

The volume of air spaces in a plant is comparatively largest in those which grow in water and in moist places, where their buoyancy is thus secured, and also in many plants found in dry places, as *Composite* (sunflower), *Umbelliferæ* (hemlock), *Labiata* (mint), and in grasses and lilies with hollow stems, or hollow leaves, as in leaks and onions. Hollow stems afford sufficient strength to enable plants to attain a considerable height, with a small expenditure of material.

* Dry atmospheric air contains the following percentages :—

Nitrogen, by weight,	77
Oxygen,	23
Carbon dioxide, by volume,	0004
Ammonia,	000001

The proportion of watery vapour varies in undried air from 0 to 3 per cent. by weight.



The various species of bamboo and the stems of the *Lilium giganteum* which are used by hill men as trumpets, afford good examples, also the huge *Umbelliferæ* of Afghanistan.

Air spaces may be classed as—

Interstices.

Cavities or lacunæ.

Passages, chambers and hollows.

In *interstices*, the space left is less than the diameter of the adjoining elements.

Cavities are about equal in diameter to the adjoining elements.

Passages, chambers, and hollows have a much larger relative volume than the adjoining elements.

Tissue permeated by air spaces may be termed *lacunar, chambered, &c.*, whilst that with only small interstices is relatively *dense*.

In dense tissue, the interstices occur between the round corners of the cells, which by their expansion have lost their original polyhedral shape, &c., by the splitting asunder of their walls, and have given rise to interstices.

Lacunar parenchyma may be due to unequal growth in cell surfaces after leaving the condition of meristem, such as the *stellate tissue* common in water plants, and in many monocotyledons, as the plantain, also in the pith of rushes; this kind of stellate tissue is rare in dicotyledonous plants.

Wide air-containing chambers and canals, of which the diameter greatly exceeds that of the surrounding

Wide air containing chambers. cells, are produced in two ways:—

- (i). *Schizogenetic*.—By separation of permanent tissue elements, owing to the splitting of their common walls.
- (ii). *Lysigenetic, or rhexigenetic*.—By dissolution or rupture of certain transitory cells.

The large air spaces in the stem and roots and leaves of many water plants, such as the water lily, belong to the first kind, whilst to the latter belong the air passages and hollows of grasses, *Umbelliferæ, Labiata, &c.*, such hollows being frequently closed by diaphragms at intervals, along the internodes, as in water lilies, or at the nodes, as in bamboos.

Certain cells resembling hairs project into the large lacunæ of



the air passages, which may be either glandular hairs, or like bast fibres. They are found in water lilies, ferns, and arums.

Where intercellular secretory reservoirs exist, we find the spaces

Intercellular secretory reservoirs. originally surrounded by cells, which subdivide, forming a number of closely packed cells smaller than those of the surrounding tissue. These cells secrete resin, oil, gum, &c., and by the rupture of the cell walls bordering on the reservoir, pour their contents into the latter.

The close fitting lining of small cells around such an internal cavity is termed *epithelium*.

The resin passages in the primary cortex of *Abietinæ* may be traced back to a row of initial cells, which sub-divide into four cells each, and these latter separate at the point of contact to form the passage.

As the plant grows, there occurs a widening of the passage, and a growth of the enclosing cells in a direction tangential to its surface, together with an increase in the number of these cells by radial sub-division, from four, to six or eight in *Pinus*.



CHAPTER IV.

THE ARRANGEMENT OF THE DIFFERENT FORMS OF TISSUE.

THE various forms of tissue springing from the primary meristem have a definite relative position and arrangement.

Primary arrangement. In many cases, this is permanent, as in most leaves, stems and roots, and in plants other than dicotyledons and gymnosperms.

In the latter orders, either new structures from secondary meristems are formed in addition to those from the primary meristem, or changes appear in the primary tissue consequent on these secondary formations.

The epidermis has been already described, and beneath it we have a tissue termed the *hypoderma*, but it will be better here to describe the tracheæ and sieve tubes, which are united into strands and vascular bundles forming a well marked skeleton of the plant, round which the other tissues arrange themselves.

As besides tracheæ and sieve tubes, bast fibres are frequently found in these bundles, they are best described, as *fibro-vascular bundles*.

Thus, four elements may be found in these bundles :—

- (i). Bast fibres.
- (ii). Tracheides or wood fibres.
- (iii). Vessels.
- (iv). Sieve tubes.

In conifers, the bundles only contain tracheides, except in the medullary sheath, where vessels are found ; in monocotyledons, vessels are few in number.

Scattered tracheides occur in some plants outside the fibro-vascular bundles, and in epiphytic orchids, **Isolated tracheides and sieve tubes.** (*Aerides oderata*,) and arums, (*Pothos*,)

THE ARRANGEMENT OF THE DIFFERENT FORMS OF TISSUE.

we find a sheath of tracheides under the epidermis of the sub-aerial roots.

When the root of these plants first emerge from the root-cap, a delicate cuticle is present, but this is not found continuously on the mature root.

This absence of a cuticle, as well as the provision of a sheath of such absorptive material as woody fibres, secure a supply of water for epiphytic orchids, whenever it rains.

Sieve tubes are found in the pith of many plants, such as the tobacco, potato, &c. They are also found outside the fibro-vascular bundles of the stems of gourds.

In roots of the higher plants, a bundle terminating with the growing point, and growing with it, is found along the axis.

Arrangement of the fibro-vascular bundles:—In the root,

In the centre of this bundle a mass of parenchyma is sometimes found, resembling a pith, but its elements are much smaller and without intercellular spaces.

In the thick roots of certain palms and in *Pandanus*, a number of parallel bundles are found uniting in the growing point. Also in the roots of the yam (*Dioscorea Batatas*), and a few other plants.

In young roots, the fibrous central bundle is readily separated from the soft surrounding tissue, and, in Canada, the fibrous roots of the spruce are used for sewing together the birch bark canoes.

In the stem. There are two kinds of bundles in stems—

- (i). Those that always remain in the stem and grow acropetally, or from beneath upwards, with it.
- (ii). Those bundles which pass from the leaves into the stem, and thus belong in one part of their course to the stem, in another part, to the leaf.

The former are termed *cauline bundles*, and the others *common*, or leaf trace *bundles*. The latter originate at the point of insertion of a leaf with the stem or branch, and grow upwards into the leaf, and downwards into the stem.

A stem may contain only cauline, or only common bundles, or both.

The bundles generally follow the direction of the longitudinal axis of the stem, it being only in the nodes, and in some unimportant branches, that a transverse direction is adopted.

After traversing a certain distance, a bundle may connect itself



with another to form a single one. Thus we have separate and united bundles.

From the point of exit in the node, the common bundle passes downwards through several internodes until it joins another bundle, which junction generally takes place at, or near a node. It is this junction of many bundles at the nodes, and also the transverse crossing of bundles from one side of the stem to the other, which gives the node its hard knotty texture. The length of stem between two nodes is termed an *internode*, and it is only from nodes that leaves or normal buds arise.

Leaves are lateral appendages of stems, and when fully developed consist of the following parts:—

Sheath, including *stipules*, *petiole*, and *lamina*.

The common bundles represent, within the stem, the union of certain strands of the leaf skeleton. They are, therefore, termed bundles of the *leaf-trace*, and for any leaf may consist of one, or many bundles. These leaf-trace bundles are single in pines, and consist of several hundred bundles in the leaves of palms, the large leaves of which evidently require to be connected very substantially with the parent stem.

A leaf-trace with many bundles may be of variable width, for example, it may take up from $\frac{1}{10}$ th of the circumference of the stem, to $\frac{1}{2}$, or the whole circumference in the case of many palms.

Hence, in palms with petioles forming sheaths around the stem, each leaf-trace forms a cylinder surrounding the cylinders of leaf-traces from upper leaves.

The arrangement of the bundles may constitute the following types:—

- (i). Type of the dicotyledons.
- (ii). Anomalous ,,
- (iii). Type of monocotyledons.
- (iv). Phanerogams with axial bundles.
- (v). Fern-like plants.

To the first type, a great majority of the dicotyledons belong, and most of the *Coniferæ*; among the monocotyledons, many *Dioscoreæ* (yams), and amongst cryptogams, *Equisetum* and *Osmunda*.

Here, all the primary bundles springing from the primary meristem are common leaf-trace bundles.

The bundles curve inwards into the stem at the nodes, and from thence, they take a radially perpendicular course down it, remaining at about the same distance from the middle and from the surface of the stem.

The bundles generally pass through more than one internode, and unite with those which are lower down the stem, at, or close to a node.

Such primary stems are found in annuals, and in the young first year's shoots of woody plants.

From this course of the bundles results the characteristic primary stem of these plants.

The bundles are arranged in a transverse section of the stem in a broken ring-like series, termed the ring of fibro-vascular bundles, the remaining tissue in which they are embedded, chiefly parenchymatous, being separated into—

- (i). An axial cylindrical, or prismatic body, termed *pith* or *medulla*.
- (ii). A mantle covered by the epidermis outside the ring is the *outer cortex*.
- (iii). The bands lying between the bundles, and passing radially from the cortex to the pith, are the *primary medullary rays*, the number of which in any particular case is the same as that of the leaf-trace bundles.

If we draw a diagram representing the course of the bundles in any particular stem, we find that, those from an upper leaf join those of lower ones according to a definite arrangement.

Thus, in the sunflower, the bundle from No. 6 leaf joins that of No. 1, and the bundle from No. 7 joins No. 2, and so on, each passing through four internodes, before uniting with a bundle of a lower leaf. In this way it will be seen that, a perfectly symmetrical arrangement of the bundles exists.

If we take a sunflower stem and notice the arrangement of the leaves on it, we find that, the 6th leaf is over the 1st, and the 7th over the 2nd, and so on, the leaves being spirally arranged along the stem.

If we draw a spiral line round the stem passing in succession



through the base of each leaf, we find that, in passing from No. 1 to No. 6 leaf, we have circled the stem twice. If then, we take a fraction, of which the numerator is 2 and the denominator 5, corresponding to the number of times we have encircled the stem, and the number of leaves met with, before an upper leaf is exactly over a lower one, the fraction $\frac{2}{5}$ represents what is termed the *Phyllotaxis* of the sunflower. This fraction also shows that, the horizontal angle between two adjacent leaves is $\frac{2}{5} \times 360^\circ = 144^\circ$, and all the leaves in the stem are in five rows.

It will thus be seen that, leaves are developed *acropetally*, the youngest being nearest to the terminal bud of the shoot, and the oldest, furthest down. In certain cases, two or more leaves are developed simultaneously at a node, and form a *whorl*, the leaves being said to be *opposite*, or *verticillate*.

In the case of leaves in spirals, the arrangement is said to be *alternate* or *spiral*.

When leaves are arranged in verticils, or whorls, round the stem,

Verticillate arrangement of leaves. consisting of two, three, four or more leaves, they are said to be *opposite*, *ternate*, *quaternate*, &c.

Opposite leaves are also termed *decussate*, as they occur in pairs, on opposite sides of the stem, the leaves being all in four rows.

The teak gives an example of decussate phyllotaxis, and, generally, so do plants of the families *Cornaceæ*, *Caprifoliaceæ*, *Rubiaceæ*, *Oleaceæ*, *Apocynaceæ*, *Verbenaceæ*, &c.

Ternate leaves occur in the oleander, and leaves in verticils of five or seven in *Alstonia scholaris*, both belonging to *Apocynaceæ*.

If leaves are disposed alternately on either side of the stem, the **Spiral arrangement.** phyllotaxis being $\frac{1}{2}$, they are termed *distichous*, and this arrangement prevails with grasses, also in elms, and in many *Urticaceous* and *Tiliaceous* plants.

Plants with the phyllotaxis $\frac{1}{3}$, are termed *tristichous*, and this is always found in sedges.

It is found that the following series includes all phyllotaxes :— $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, $\frac{8}{21}$, &c., the numerators being formed by the addition of the two previous numerators, and the denominators by the addition of the two previous denominators.

The pentastichous arrangement ($\frac{5}{2}$), is common in *Cupuliferae* as in oaks, also in *Rosaceae* (pears), and many forest trees.

In the case of the more complicated phyllotaxes, when the internodes are very short, as in the date palm, and in pine and fir cones, it is very difficult to trace the primary spirals, but a number of secondary spirals are readily visible running from left to right and from right to left. If we take the lowest number of these secondary spirals in the two directions, as the numerator, and the total of them as the denominator, the fraction thus formed will be the phyllotaxis of the plant, and the proof of this is given in Asa Gray's Botany, pages 127—128.

Fascicled leaves occur in a tuft, and really spring from a suppressed branch and not from a node.

They are common in conifers, and different species of pines may be distinguished according as their needles occur in clusters of two, three or five. Thus *Pinus longifolia*, *Gerardiana*, and *Kasya* have their needles in threes. *Pinus excelsa* has them in fives, while *Pinus Merkusii* of Tenasserim, has them in pairs.

The normal leaves of pines formed on young seedlings are much smaller than those fascicled needles, which spring out of the axils of the former.

The primary bundles of some dicotyledons are not arranged in a simple ring, but additional bundles occur in the pith, or in the cortex; or the bundles are arranged in several circles; or are irregularly scattered amongst the other tissues, except the very outer one, which forms a well marked ring.

These exceptions are found in the gourd family, also in some of the *Umbelliferae*, in the pepper family, also among water lilies and some other plants.

These anomalous forms may be distinguished as having—

(i). *Medullary bundles.*

- (a). All bundles belong to the leaf-trace, some being arranged in the typical ring of the stem, whilst others are scattered, or arranged in rings in the pith, as in gourds and peppers.
- (b). Similar to (a), except that the bundles form a network throughout the stem, as in water lilies.



- (c). Besides the ring of leaf-trace bundles, cauline bundles are found in the pith of begonias, of some *Umbelliferae* and *Araliaceae*.

(ii). *Cortical bundles.*

Young foliage shoots of *Casuarina* and certain melastomas and cactuses have leaf-trace bundles in the cortex through one internode, as far as the next node.

The stem of most monocotyledons does not show bundles in a transverse section arranged in a simple ring, but within an outer zone of cortex devoid of bundles, there is a circular surface, in which several concentric irregular series of bundles are arranged (i), around a central portion without bundles, which later become hollow, as in the stems of many grasses, bamboos, &c.

Or (ii), the bundles lie scattered over the whole surface.

In considering the longitudinal section of a palm, we find that, the bundles from each leaf pass transversely towards the centre of the section, and then turning outwards approach its periphery, and pass perpendicularly downwards, till they unite with the bundles below.

The cortex of most palms is extremely fine, and is obscured by the persistent bases of the leaf-petioles.

The existence of this cortex, in many cases, appears to be doubtful, and in the bamboo, for instance, merely the epidermis surrounds the outer bundles.

All bundles do not proceed to a similar depth, and it is found that, the middle bundle of the leaf-trace penetrates the deepest, and others less deeply, the further they are from it, whilst the marginal ones proceed almost perpendicularly down the stem.

If we take a piece of a decomposing palm stem, we find that, the parenchyma decays much more readily than the hard tissue of the bundles, and that the course of the latter may, therefore, be readily traced.

We find that, certain bundles of larger size than the rest are obliquely inclined, whilst the majority of the bundles proceed parallel to the axis of the stem. These large oblique bundles have come from a leaf close to the position in which they are

found, and lower down the stem become smaller and parallel to the axis.

This arrangement of the bundles attaches the leaves firmly to the stem, and in many palms, the leaves are of enormous size, sometimes 30 or 40 feet long, as in certain South American palms, and would be easily stripped off in a storm, if their fibro-vascular bundles simply passed along the outer margin of the stem.

Palm leaves do not separate neatly at the leaf scars from the parent stem, as do those of dicotyledons, by the formation of a layer of cork at their base, but decay gradually from above downwards, leaving their persistent petioles on the stem.

It is owing to these bases of fallen petioles that, the rough surface of the date and other similar palms is due, whilst in palms with sheathing petioles, as the sago and areca palms, and in canes, the stem is more or less smooth, with rings above the nodes.

It is evident, when we consider the nature of this arrangement of bundles that, in any transverse section of a palm stem we shall only meet with a comparatively few large bundles in the centre, and these from leaves near the section, as the bundles proceeding from leaves somewhat higher up the stem have already approached the periphery. Hence the number of bundles in the sections gradually increases from the centre to the circumference, whilst their size gradually decreases. It is evident, therefore, that the hardest part of a palm stem is its outer portion where the bundles are close together, whilst though the centre of the stem contains the largest bundles, they are surrounded by a mass of parenchyma, which containing starch and other decomposable substances is peculiarly subject to decay and attacks of insects. Hence, it is merely the outer parts of a palm stem, as in scantling sawn from the palmyra, and not the centre, which are used for building purposes, and owing to the rapid decay of the centre of a palm stem, in many cases, it may be used as a tube for conveying water.

As the entire girth of an unbranching palm is produced at once from the terminal shoot, and no secondary meristem is formed, the whole of the wood of a palm is *primary wood*. Such branchless stems are more or less cylindrical, but when monocotyledons branch, as in *Dracenas*, or bamboos, they gradually taper upwards.



In monocotyledons with long internodes, such as grasses, the bundles appear to be parallel, but if we examine them in very young stems, we find the arrangement already described. In the subsequent elongation of the internodes of grass stems, from 20 to 50 times their original length, the curvature in the bundles is lost sight of.

In bamboo culms, the bundles are extremely numerous and very close together, becoming crowded towards the margin; it is, therefore, extremely easy to split a bamboo into strips, the parenchyma being very limited as compared to the bundles; the rind of a bamboo is the hardest part, owing to the silicification of the epidermis and the crowded bundles below it.

The cortex of monocotyledons is of variable thickness; in rhizomes, it is of considerable size, whilst in aerial stems it is very thin. It is doubtful, however, whether the so-called cortex of rhizomes, as in the bamboo, does not consist of the epidermis and parenchyma of the sheathing leaf-scales, which at first surrounded the rhizome.

A number of plants with reduced foliage, and roots living in water, or marshes, some monocotyledons and some dicotyledons, have their bundles united, in the centre of the stem. Among dicotyledons, we may mention *Hippuris*, and among monocotyledons, certain ground orchids.

In *Equisetaceæ*, a cryptogamous order, the bundles are arranged in a ring, separating the pith from the cortex.

In ferns, with the exception of *Osmunda*, in which we have an arrangement resembling that of dicotyledons,

Fern-like plants. we generally find an axial bundle widening out, as the stem grows stronger, into a tube closed all round, except at the nodes; here there are gaps, from the margins of which bundles pass into the *fronds*, or leaf-like branches of ferns on which the organs of reproduction generally appear.

In other ferns, we have several concentric rings of bundles surrounding either a narrow pith or an axial bundle.

The stems of ferns are generally rhizomes, but in some species growing in moist climates, as in the sub-Himalayan tract, Burma and Assam, tree ferns with stems up to 20 feet in height are met with. These stems resemble those of palms, with a crown

of fronds at their summits, and are frequently covered with adventitious roots concealing the scars of the fallen fronds. In New Zealand, after the primitive forest has been destroyed, tree-ferns form a dense growth all over the country.

Besides the bundles proceeding into the leaf, certain bundles are peculiar to the node, which are termed

Transverse girdles. *transverse girdles* and unite different bundles, and are generally more or less perpendicular to the axis of the plant, to which most of the bundles are parallel.

The bundles, which leave the stem and pass into the leaves, run, **Bundles in leaves.** as a rule, towards their margin and apex.

The bundle may run straight through without division to the apex of a leaf, as in the needles of pines.

The *nervation*, or marking of the surface of leaves, is nearly al-

Nervation of leaves. ways due to the branching of the bundles through the leaf-parenchyma. It should, however, be remembered that, the marks we see on the surface of the leaf may not refer to the inner structure, and in the leaf of the agave, for instance, the vascular bundles are sunk within the parenchyma of the leaf and give rise to no external nerves.

In the case of fossil plants, the leaf is frequently marked on sandstones and shales, and by its nervation, we may distinguish one class of plants, and one species, from another. Also in ferns, the markings on the fronds, which serve the purposes of leaves for these plants, are used to classify them.

The middle portion, or *rachis*, of compound and deeply divided leaves, and the midribs of most large leaves, receive many branches from the petioles, which pass off into the bundles of the nerves, gradually decreasing in number and size.

The bundles in the petiole, in the rachis, and in the nerves, are connected here and there with one another.

Free endings of the bundles are either found in the margin of the leaf, or in its interior.

Branches of any order may unite and give the bundle system the form of a net, when the *venation* is said to be *reticulate*.

By gentle maceration in dilute acids, all the parenchyma of a leaf may be removed, and the nervation alone remaining forms a skeleton of the leaf.

The extremely various cases of venation which arise, may be grouped into two main types—

- (i). Bundles with separate course and free ends.
- (ii). Anastomosing bundles.

The foliar expansions of all gymnosperms, with only two exceptions, the fronds of many ferns, also the rudimentary leaves of many monocotyledons and dicotyledons have bundles with a separate course and free ends ; as in the foliage of the casuarina, in which, either one unbranched bundle, or the ramifications of branched ones, traverse the expansion, and end free internally or marginally. In the leaves of conifers, there are either one or two bundles, except in *Araucaria*, *Salusburia* and a few other species, which have more branches. All pines, cypresses, and the yew have simply one bundle, while fir needles have two bundles, or very rarely, one.

Foliar expansions with anastomosing bundles may be divided into two classes—
Anastomosing bundles

- (i). Striated.
- (ii). Reticulated.

The striated type is found almost exclusively in monocotyledons, and in the leaves of a majority of these. Exceptions are arums, yams, *Smilax* and a few others.

We may distinguish two sub-divisions of the *striated* type, **Striated type of leaves** *longitudinal striation*, and *pinnate striation*.

In the former, numerous bundles run separately and parallel along the leaf, the middle ones running straight to the apex, the rest running more or less parallel courses along the blade of the leaf, but diverging more and more from the straight line, the nearer they are to the margin.

The bundles reunite towards the apex, and are also connected by little ladder-like branches, throughout their length.

In pinnate striation, numerous bundles enter the midrib of a flat leaf, and pass through it towards the apex. Then, one after another, they pass off in numerous branches into either side of the leaf, only one or few of them extending to the apex. This pinnate arrangement is found in the Indian Shot (*Canna indica*), and in plantains (*Musa sp.*)

In *Dracenas*, the arrangement is intermediary between the two.

In the *reticulated* type, the bundles after entering the leaf, undergo various orders of branching, and the

Reticulated type.

branches are distributed over the whole surface of the leaf, running in various directions, and sometimes connected into curved, or angular meshes, sometimes ending free.

With few exceptions, all dicotyledons belong to this type, as well as the monocotyledons we have mentioned before. The arums appear to be intermediate between this type and the striated.

In reticulated leaves, the bundles enter the foliar expansion in the midrib, giving off branches of the first order into the two halves of the leaf, in a pinnate manner, when the leaves are said to be *penni-veined*; or, the bundles may diverge from the base into several main bundles, giving rise to leaves *palmately-nerved*, as in maples and *Sterculias*, *peltately-nerved*, as in *Tropæolum*, and *tri-nerved* as in *Vitex Negundo*.

In some leaves, as in those of *Ficus elastica* and some *Myrtaceæ*, we find an intra-marginal vein, in which all the lateral veins terminate, and beyond which, is a band of parenchyma only, or very fine nerves. We should distinguish between *simple* or *entire*, and *compound* leaves, the latter being divided into *leaflets* or *pinnae*, with a common petiole or rachis. They are sub-divided into the *palmate* and *pinnate* types, the leaflets themselves following one of the types already given, and being either striated, or reticulated.

In palmate leaves, the leaflets are all at the end of the common petiole, as in the horse-chestnut, or the palmyra. Pinnate leaves may be *bi*, *tri*, *quadri*, &c., pinnate, according as the *pinnae* are themselves sub-divided. They are *impari*, or *pari* pinnate, according as they have a terminal pinna or not, the former kind occurring in *Cedrela Toona*, and the latter in the *ritha* (*Sapindus detergens*).

Numerous forms of pinnate leaves occur in the *Leguminosæ*, of which the *Acacias* and *Albizzias* are good examples.

The normal branches of dicotyledons and gymnosperms are

Branches of leafy stems. nearly always axillary, that is, they spring from a bud situated in the axil of a leaf.

The primary bundle system of these axillary branches is inserted on that of the leading shoot in different ways.

The commonest mode of insertion is that in which the bundles

of the branch at the point of insertion are united into one or two bundles, which unite themselves at the node of the leaf below the shoot on bundles of the leading shoot bordering the gap formed by the leaf in the bundle-ring.

Or, the bundles, instead of uniting at the nodes with those of the leading shoot, proceed downwards to a lower node, where the union takes place.

In both these cases, the piths of the leading and lateral shoots are in direct connection.

The modes of union in the bundles, in the case of *Umbelliferae* and cactuses, need not be described here.

In palms, dracenas, lilies, arums and orchids, the numerous bundles of the normal axillary shoots enter into the bundle cylinder of the main shoot at the nodes, and pass downwards and inwards with the bundles of the leaf below the shoot, and insert themselves on them.

Axillary buds will be in verticils at a point, if the leaves are opposite or verticillate, as in the *Rubiaceae*, including the haldu (*Adina cordifolia*), and other forest trees.

There may also be one or more *accessory* buds situated below the larger *axillary* bud, as in the honeysuckle (*Lonicera*). In oaks, and some other plants, we find *false verticillate* buds, produced in the axils of the bracts at the end of each year's shoot, where the internodes are greatly reduced in length.

Any shoot from an axis, which is not developed in a normal way, is said to be *adventitious*.

It is a general rule for adventitious shoots that, their bundles should be inserted on those of the main axis, nearest to their point of origin.

Hence, in making slips of plants, we find that adventitious roots are developed more readily at the nodes, where the bundles form a knotted mass, and also in a begonia, or other plant, the leaves of which may be made to give out adventitious roots, it is from the union of the strong nerves that these roots are produced.

Roots are found as lateral branches, on members of their own kind, as well as on stems, and rarely on leaves.

Lateral roots are invariably of *endogenous* formation, that is, originate in subjacent tissues and pierce through the outer ones, their

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vascular bundles being inserted directly and without branching on the nearest one of the main axis, or dividing into branches, which connect themselves with several bundles of the axis.

The former simple case occurs in almost all roots of dicotyledons and in those of ferns.

The splitting of the bundles of the root into several shanks, which insert themselves in several bundles, is common in monocotyledons, but there are a few exceptions, as in the case of sedges.

Vascular bundles are strands consisting of tracheæ and sieve tubes, as their essential parts. Both are accompanied by parenchymatous and often by sclerenchymatous elements, such as bast fibres.

Structure of vascular bundles. During its course through a plant, a bundle undergoes considerable changes, thus, sections of the same bundle in different places may vary greatly.

Owing to these differences in the bundles, we distinguish between *bundle ends* and *bundle trunks*, the latter belonging chiefly to the stem, roots, leaf-stalks and thick nerves in the leaves.

In a few cases, we find that, the essential organs of the bundle trunks either disappear, or remain elementary, and here, we distinguish between *complete* and *incomplete* bundle trunks.

The tracheæ and sieve tubes in bundle trunks are arranged in two or more groups, all the tracheæ uniting to form one group, whilst another, or in rarer cases, more than one unites all the sieve tubes. Thus, in every bundle, we may distinguish *xylem*, or the part containing the tracheæ, from the part containing the sieve tubes, termed *phloem*.

Besides the two essential elements, tracheæ and sieve tubes, we find rows or layers of cells placed between them, and these are always found in the phloem, though they may be absent in the xylem.

The external surface of the vascular bundles is generally separated from the surrounding tissue, by a *bundle-sheath*, which may occur—

In the form of an *endodermis*.

In the form of strands of fibres, or of sclerotic cells, bordering the bundles on one side, or encircling them.

We may, therefore, either include these fibres with the bundles under the term *fibro-vascular bundles*, or we may speak of them as forming a sheath between the bundles and the parenchyma.



The elements of the bundles are connected together without intercellular spaces, except along their outer and inner edges. We find air cavities along the inner edge of the xylem, and secretory spaces along its outer edge, and that of the phloem.

According to the arrangement of the xylem and phloem, three main forms of bundles may be distinguished as—

Collateral, Concentric, and Radial.

Collateral vascular bundles are found in all stems and foliage leaves of phanerogams, with rare exceptions, and in the stems of most of the higher cryptogams.

They are very rarely found in roots.

In the commoner cases, we find xylem inwards and phloem outwards.

In dicotyledons and gymnosperms, all the xylem forms an annular zone surrounding the pith, while the phloem forms an external zone.

The former, together with the secondary formations, form a *woody ring*, while the latter forms the *liber*, or *soft bark* of a stem.

The same arrangement is found in the stem of monocotyledons, and in those leaves, in which the bundles are placed in a ring round a central part, from which they are absent.

In leaves, where the bundles are not in a ring, their phloem is turned towards their true lower surface, and the xylem towards their true upper surface, the real nature of these surfaces being sometimes concealed by torsion of the petiole, as in the vine.

As regards the number of elements in each part, and the thickness of the bundle, we find wide differences. Many sappy herbaceous plants, especially monocotyledons, as the plantain, and water and marsh plants, have only three to six tracheæ in their xylem, and their phloem consists of 20, or fewer elements; in the leaf stalks of many arums, we may only find one or two tracheæ in the bundles, whilst in palms, ferns, and dicotyledonous land plants, the elements may be very numerous.

The xylem is built up of tracheæ and cells. At its inner edge, we find a few spiral, or annular vessels, which may be termed *primitive elements*.

Structure of the xylem.

These primitive elements are frequently compressed and some-

times destroyed by the pressure due to the growth of neighbouring elements.

In *Coniferae* and other gymnosperms, no vessels are found in the xylem, except the primitive elements.

As we proceed outwards, we find vessels and tracheides, with successively denser walls ; first, spiral and annular, then, reticulated and pitted.

In monocotyledons, the tracheæ are generally arranged in two main rows like a V, in the midst of which, we generally find the phloem.

The large vessel, which is found in every bundle of the common cane, is a pitted vessel, all the other vessels in the bundle being narrow and spiral.

The phloem of collateral bundles consists of sieve tubes and **Structure of the phloem.** of thin-walled elongated prismatic cells, termed *cambiform cells*, the walls of which have a tendency to swell, when moistened.

The boundary between the phloem and xylem is in most cases sharply marked, owing to the contrast between the delicate and non-lignified membranes, on the one hand, and the thickened and lignified membranes, on the other.

As an illustration of this, we may cite the ease with which bark may be stripped off a young stem, the section taking place at the junction of the xylem and phloem.

In dicotyledonous plants, the cells on this border surface long remain capable of division, the divisions taking place chiefly in the tangential direction parallel to the outer edge.

In case secondary growth should take place, as in dicotyledonous and gymnospermous woody plants, this border zone retains its capacity for division, and becomes a portion of the *cambium ring*, the remainder of which is developed in the primary medullary rays, and is termed *interfascicular cambium*, while that portion between the phloem and xylem of the bundles is *fascicular cambium*.

In other bundles, the cessation of growth takes place early in each portion, after the tissues have been fully developed, and the boundary layer is therefore less clear than in the former case. Such bundles are

Closed bundles.

termed *closed*, and in monocotyledons, with closed bundles, that is, bundles which do not increase in size, after they have reached a certain development, the line between the xylem and phloem is not easily distinguished.

In the xylem of many collateral bundles, an intercellular passage occurs following the whole course of the bundle, sometimes developing so that

Intercellular passages in stems. though the tracheæ are originally formed, they become destroyed as the parts expand. This occurs in numerous monocotyledons and in some dicotyledonous water-plants, and the destruction of the xylem may be either partial, or complete, as in the leaf and flower-stalks of water lilies, while rhizomes of these plants show no cavity. In the leaves of arums, instead of the whole xylem portion of the bundle being destroyed, only certain elements share this fate, and give rise to the canals which are found in the leaves of these plants.

Sheaths of collateral bundles are either in the form of an endo-

Bundle sheaths. dermis, or of simple parenchyma; or lastly, of strands of sclerenchymatous, or collenchymatous fibres.

These may form a tube encircling the whole bundle, or a strand on the outer circumference, and, therefore, bordering on the outer edge of the phloem.

Bast fibres may even be inserted within the phloem. It is evident that hard-walled bast fibres add greatly to the strength of the bundles, in the leaf-skeleton.

In *concentric bundles*, one of the two parts occupies the middle, and is encircled by the other—

Concentric bundles. The phloem may be in the middle, surrounded by the xylem. This occurs in rhizomes of most monocotyledons.

The case in which the xylem is surrounded by the phloem is rarely found in dicotyledons, but is characteristic of the entire group of ferns, with a few exceptions.

In radial bundles, the xylem forms several bands, between which the same number of bands of phloem alternate. These are found in the stems of *Lycopodium*, and in roots, where the axial bundle is generally of a radial structure, and is surrounded by an endodermis, which may ultimately become sclerotic.

The xylem and phloem rays are separated from each other by



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delicate cells, which also surround the whole of the bundles in one, or rarely two layers, inside the endodermis.

In dicotyledons, there are generally either two, three, or four rays: more rarely six or eight, and exceptionally a still greater number. As all the side roots spring from a point opposite to one of the xylem bundles, these side roots occur in rows of two, or more, according to the number of bundles.

The zone of cells, inside the endodermis and surrounding the bundles, form what is termed the *pericambium*.

Such is the structure of primary roots of dicotyledons, but it is greatly altered by a secondary growth in thickness, which will be described further on, and in this way, they differ from the roots of ferns and monocotyledons, in which, with the exception of *Dracæna*, these secondary changes are wanting.

The sclerosis of the endodermis rarely occurs in the roots of dicotyledons.

In gymnosperms, the axial bundle of the root resembles that of dicotyledons in original structure, being altered by secondary growth.

In monocotyledons, the first thin main roots of the seedling exactly resemble those we have described, but in the stouter adventitious roots, which subsequently spring from the stem, the numbers of bundles may rise to 50, or more.

We may note the occurrence of these adventitious roots at the base of palm stems, which they increase largely in girth up to a height of several feet from the ground. In the maize, a xylem bundle is sometimes found in the centre of the root. The greater the development of the leaf surface in a plant, the more highly developed are the vascular bundles; in the stem of certain water plants, however, the bundles frequently remain rudimentary, in some cases, the whole of the xylem disappearing. Such plants require to be elastic, so as to yield to the motion of the water, and buoyant, but do not need rigidity, which the bundles afford to sub-aerial plants, and being immersed in water, do not require an elaborate arrangement of *conductive tissue*.

The ends of bundles lie either in the foliar expansions, or in the cortex, terminating either internally or at

Bundle-ends. the periphery. As the bundle proceeds further from its origin, the number and size of its elements are

reduced, except that at its extreme end a slight increase in size may be noticed. Only tracheæ with delicate cells are found at these bundle-ends, the sieve tubes being completely absent. In most leaves, the ends of the bundles are in contact with the chlorophyll of the parenchyma, the exceptions being where they lead to water pores, or to glandular reservoirs, when a group of small delicate cells covers the ends of the vessels and separates them from the epidermis. In roots, the bundle ends in the meristem of the growing point.

Plants which grow on the surface of others, but without taking their nourishment from the living tissues of their host, are termed *epiphytes*, such as many species of *Ficus*, rhododendrons, orchids, arums, ferns, &c.

Plants which obtain their nourishment from decomposing organic matter, and not from the carbon dioxide of the atmosphere, are termed *saprophytes*, such as *fungi*, and other plants devoid of chlorophyll.

Certain epiphytes obtain part of their nourishment from the decomposing bark of the tree to which they are attached, but they differ from saprophytes, in obtaining nourishment directly from the air through their chlorophyll.

Parasitic plants are such as derive a part, or the whole of their nourishment, from the living tissues of another plant, termed the *host*, to which

they are attached. Such are, among phanerogams, the mistletoe (*Viscum*), *Loranthus*, *Cuscuta*, and the *Orobanchaceæ* or broom-ropes; among cryptogams, the various species of *fungi* growing on living plants, as *Aecidium Pini*.

Pseudo-parasitic plants are distinguished from true parasites by having green foliage, or chlorophyll parenchyma in their stems, from which they partially nourish their hosts, as well as themselves.

Most pseudo-parasites are included in *Loranthaceæ*, in which family there are two types of growth. *Viscum album*, the white mistletoe, develops from seeds which are dropped by birds, such as the European missel-thrush, and is very common on apricot trees in the Himalayas. The radicle of the seed first broadens into a sort of sucking-disk, from the centre of which a fine projection

emerges piercing the bark of the twig down to the wood. This development is only possible on trees or branches with tender, corky bark. In the second year, the first *haustorium*, or root-like organ, is formed. This is the organ for absorbing nourishment, and much resembles a medullary ray, inasmuch as it is enclosed in the wood and possesses cambial tissue on the level of the cambial layer of the branch. The haustorium thus keeps pace with the yearly growth of wood and cortex. In addition to the haustorium, a number of side-roots or *bark-roots* develop in the young phloem of the host. These grow down the length of the branch, but without touching the cambium layer. The result of this is that, the pointed root-tip covered with its sheath destroys the phloem elements lying in its course. Either every year, or now and then, but rarely twice in a single twelve-month, from near the point of the bark-root, on its inner side, a new haustorium is given off, and subsequently displays exactly the same growth as that which has been already described for the first haustorium. The whole series of haustoria, whose ages can be told by the number of annual rings from which they grow, serve for taking up water and mineral nutriment from the wood. The duration of the haustoria and bark-roots depends on the species of the host, and on the length of time which elapses before the formation of *rhytiderm* (secondary bark). By this formation, the external fibrous layers soon fall off and die, whilst a quick production of new bast takes place at the cambium. Thus the bark-root is pushed out until it falls off, and the haustoria, from which it is now severed, die, and become surrounded by the woody layers of the host. In this way, the oldest portions of the plant cease to exist, whilst the youngest parts still remain alive. The haustoria still connected with their bark-roots die proportionately to the advance of the heart-wood, though they remain alive and active in the sap-wood. This is due to the capacity which the latter possesses for conducting water. On the external surface of the bark-root buds exist, and develop shoots outwards through the bark. These shoots often take an impetus from the fall of older and neighbouring portions of the plant. They root themselves independently, and thus a heavy crop of mistletoe may develop on one tree. The only measure which can be adopted against mistletoe is to cut off the twigs attacked by it.



Another type of growth is shown by various species of *Loranthus*, of which *Loranthus longiflorus* is extremely common on Indian trees, especially on the mango and the sál.

These plants usually send down only three strong roots, termed *borers*, to the cambium zone. These borers take up nutriment directly from the wood without the mediation of haustoria, and this action is rendered possible by means of a peculiarity of growth. The wedge-shaped root point, covered with its capsule, grows in the cambium of the newly-formed wood, and runs parallel to the length of the wood-elements. It splits these apart, and exercises a pressure on the inner wood-elements, without, however, injuring them. It also compresses the cambium cells, and to a greater extent on the external side, so that they are killed by the pressure. The organs can only be split by the borer so long as they are still young and unligified. The growth of the borer must cease so soon as, in consequence of the development of the annual ring, the tissues become by lignification so capable of resistance, that they no longer allow themselves to be rent by its wedge-action. There arises on the external surface of the latter, at about $\frac{1}{4}$ inch behind the point, a new borer, which continues to grow in the cambium and young wood until it is checked, when again a new root-point is formed, as before, to follow the tender region of most recent growth. In this way, every year, three graduated protuberances are formed, and it is at these steps that the water and nutriment directly enter the borer. The root yearly thickens on its outer side to the breadth of the new annual ring. Rarely after four years, and usually only after eight years, or later, its thickening ceases, and it becomes enclosed in the wood, without its functions, or vitality, being affected, while the youngest portion continues its growth undisturbed. From such deep-lying roots, shoots may spring and develop new roots in the cambium-tissue. The part of the branch on which the *Loranthus* is rooted soon swells up, and may develop into a large tumour. The result is that, the portion of the branch above it withers, and frequently dies. Cutting off the attacked twigs is the only remedy available.

As the wood of the *Loranthaceæ* is much softer than that of their hosts, and more liable to decay, we find cup-like cavities in wood attacked, where the roots have decayed and been absorbed.

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The plants belonging to the family of the *Cuscutæ*, or Dodders, are true parasites, and in India are very destructive to orchard and roadside trees, and to shrubs and other low forest growth. The seeds sprout in the ground, and if the long filiform climber does not find a suitable host, the young plant soon dies. The climbing stem surrounds a tree spirally, and pierces the bark with numerous haustoria. The ground root afterwards dies, and the plant supports itself by drawing nourishment from its host. Weak plants thus attacked are soon killed, and even stronger ones are checked in their growth. The parasites growing on shrubs and hedges should be destroyed.

It has been found that the sandal (*Santalum album*) in many cases commences life, as a parasite, on the roots of other plants, though it subsequently becomes independent of them, and may grow independently from the first.

Another parasitic genus, *Orobanche*, a species of which is common on the tobacco in Southern India, and another in wheat fields in Northern India, has tuberous rhizomes in contact with the roots of the host on which it is growing, and here the vascular strands of both become broken up into numerous small strands immediately in contact.

An account of cryptogamic parasites will be given further on.

The primary parenchyma forms the principal contents of the **Arrangement of** space enclosed by the epidermis, where it is left free by the bundles.
chyma.

The *external cortex*, the *pith* and the *medullary rays* of stems, as well as the greater mass of the tissue in foliar expansions, are built up of parenchyma.

The parenchyma of the pith generally consists of cells arranged in longitudinal rows, which when young contain starch and other products, and in foliage shoots, frequently chlorophyll. They either preserve their condition throughout life, or else, as in many dicotyledons, they dry up and die.

Lacunæ frequently appear in the pith, which in many stems, owing to the absorption of the surrounding cells, give rise to wide axial canals, or to chambers with diaphragms, at intervals along the internodes, or merely at the nodes.

In most dicotyledonous stems, the cells of the pith are widest at



the centre, and narrowest near the vascular bundles, where they form the *medullary sheath*, which is frequently taken, in old stems, to include the primitive vascular elements.

In monocotyledonous stems, as in the múnj grass (*Saccharum Munja*), we also find narrow celled parenchyma surrounding the bundles. In other respects, the parenchyma of monocotyledons resembles the pith of dicotyledons, containing starch and other products, and it is thus much more liable to decay than the bundles.

In primary medullary rays, the same conditions are found, as in the periphery of the pith, the elements becoming narrower where they approach the bundles.

In most cases, and especially those in which the stem bears well developed foliage leaves, that part of the cortical parenchyma which borders on the epidermis becomes denser and contains thicker-walled elements, which may become either sclerotic or collenchymatous, than the inner portion, the cells of which become wider towards the interior, having between them interstices filled with air. This outer tissue is termed the *hypoderma*.

- (i). The only interruption in the hypoderma in numerous plants, such as species of *Cactus*, *Euphorbia*, &c., occurs where stomata are present, and in this case, the hypoderma forms a closed cylinder of many layers surrounding the stem.
- (ii). In another case, the hypoderma is in longitudinal bundles terminating with thin walled parenchyma, the former usually occurring at projecting corners of the stem, as in *Labiatae*, *Umbelliferae*, *Malvaceae*, &c.
- (iii). A collenchymatous hypoderma lines the epidermis, except where the thin-walled loose parenchyma breaks through, near the stomata. This form is found in most dicotyledonous woody plants, as in *Acer* and *Salix*.

In weak stems, as those of water plants, the hypoderma is almost entirely absent.

The thin-walled cortical parenchyma contains chlorophyll, except in a few plants which are destitute of it, such as certain root-parasites, and the nearer the surface, the greater is its amount.

Cortical parenchyma.



As already stated, the parenchyma is traversed by air spaces, which attain large proportions in water plants.

In those plants which have no foliage leaves, or in which they are not fully developed, or of very transitory duration, as in *Cocoloba*, *Euphorbia Royleana*, *Caparis aphylla*, *Orthanthera viminea*, &c., the stem has to do the office of the foliage, and the inner cortical parenchyma, in this case, assumes the structure of the chlorophyll bearing layers in leaves, which we shall describe further on. Such leaf-like stems are termed *phyllo-clades*, or *cladodes*.

The petiole is absent in many leaves, as in those of agaves

and aloes, whilst in several Australian

Phyllodes. acacias, as in *A. Melanoxyton*, the pinnate leaf of the young plant becomes gradually converted into a simple leaf, from which the pinnæ have disappeared, and only the flattened out petiole remains, the leaf thus modified being termed a *phyllode*.

Phyllodes are generally arranged vertically, so as to diminish transpiration in a dry climate, where the plants bearing this kind of foliage abound.

The space in the lamina of leaves unoccupied by the nerves, is filled with parenchyma, which may be termed *mesophyll*.

All kinds of foliar expansion, such as phyllodes, phyllo-clades and *halms*, or monocotyledonous stems, such as those of onions, resembling leaves, have a similar structure as regards their parenchyma, which is generally chlorophyll parenchyma.

We may distinguish between two types of leaves, the *centric* and *bifacial*.

In the former type, the chlorophyll parenchyma is uniformly distributed throughout the leaf, except
Centric type of leaves. where bands of other tissue intervene.

To this type, in which there is very little or no difference between the two surfaces of the leaves, belong cladodes, halms, and flat foliage leaves arranged vertically, as the phyllodes of Australian eucalypti, acacias, leaves of aloes, agaves, grasses, &c.

The cells of the chlorophyll parenchyma are either elongated transversely, that is, parallel to the surface, or elongated prismatically or cylindrically vertical to the surface, and in this case the name *palisade parenchyma* is applied.



There may be several rows of these palisade cells, those of each row being nearly of the same height, and at their junction numerous intercellular spaces are left.

As the distance from the epidermis increases, the palisade form passes into a roundish one.

We may distinguish between two kinds of the centric type of leaves.

(i). The whole parenchymatous mass of the leaf being chlorophyll parenchyma, which towards the middle of the leaf is larger celled, poorer in chlorophyll, and more often traversed by large air *lacunæ*; the leaves of most grasses belong to this type.

(ii). The chlorophyll parenchyma forms a zone near the surface of the leaf, in which we find a middle layer more or less free from chlorophyll consisting of large colourless cells, full of cell sap or mucilage, and sometimes serving as a reservoir for starch, as in the thick fleshy leaves of the agave. In certain variegated leaves, this colourless tissue breaks through to the surface.

The stripes of yellow in the variegated agave are really due to a change in the colour of the chlorophyll from green to yellow, and not to this colourless parenchyma appearing on the surface.

Leaves of the agave, aloe, cactus, pine, many eucalypti, acacias, casuarina, &c., and many monocotyledonous leaves are examples of the second type.

In the bifacial type of leaves, we have nearly all flat horizontal

Bifacial type of leaves. leaves, and nearly all leaves of this kind.

In these, the chlorophyll parenchyma forms the entire substance of the leaf, being severed into two distinct layers, one corresponding to the upper surface, and one to the lower surface of the leaf; it is, therefore, termed the *bifacial type*.

The difference between the two layers is that, in the one belonging to the surface turned upwards, the parenchyma is denser than in the lower one, with less wide interstices, and therefore appearing of a darker green. Generally, the denser layer is formed of one or more layers of palisade cells, whilst the lower layer consists of spongy parenchyma. In other cases, the cells of both layers

are of irregular form, and only differ by the number and size of the air cavities of the lower one.

In order to distinguish the upper from the lower surface of a leaf, the only direct guide is to follow the course of the xylem and phloem in the midrib of the leaf. The xylem is uppermost in the true upper surface of the leaf, but it frequently happens that the petiole becomes twisted, so as to bring what is really the lower surface uppermost, as in the vine, and in this case we find the loose parenchyma in the true upper surface of the leaf.

The denser layer in bifacial leaves is, as a rule, less thick than the spongy layer; in many leathery leaves, scarcely half as thick. The line of the partition between the layers is usually well marked off, though sometimes one form passes gradually into the other.

We may also note that, the chlorophyll becomes more abundant, up to a certain point, with the increasing age of a leaf. Every one has noticed the varied appearance of young foliage, due either to the masking of the chlorophyll by reddish colouring matter, or to the scantiness of the chlorophyll grains.

A mango grove in April presents a variety of bright colours, which are all reduced to an intense green in August.

Besides the parenchymatous masses in leaves already described, we find in many tough leaves, as in leaves. needles of conifers, a single or many layered hypoderma, no doubt the continuation of that of the petiole and stem.

This hypoderma forms a strengthening layer to the epidermis, and resembles in its nature the epidermal cells, or it may be collenchymatous; it is only interrupted at the stomata, in most cases, but in many grasses it forms narrow bands.

The primary cortical masses of the root consist chiefly of parenchyma, the cells of which are arranged in vertical rows, as in the meristem of the root.

We may distinguish between two layers, an outer and an inner one. The former consists of cells closely united, whilst in the inner layer, large lacunæ and air passages are found. The fibrous thickening in the walls of the elements found in orchids and conifers belong to the inner layer.



The root-cap always consists of parenchyma, which in the younger stage is full of starch with its parts closely connected together.

Root-cap.

In most roots, a very large number of layers are produced.

The outer layers die and fall off, or disappear, by degradation of their walls into mucilage, when they are dissolved by the water of the soil, and in either case are replaced by new layers from within. The removal of the outer layer is expedited by the passage of the root through rough soil.

In most water lilies, the root-cap is persistent.

It has been already stated that, where two kinds of tissue are

Sheaths. in contact, one of which is parenchyma, its cells become gradually smaller as they approach the other tissue, and especially when the latter is fibro-vascular.

As the bundles in roots correspond to the primary plerome, the sheath surrounding the latter may be termed the plerome sheath, and is continued from the root upwards through the stem, outside the fibro-vascular bundles, and encloses strands of bast fibres, as well as the vascular bundles themselves.

This plerome sheath is found in two forms.

In the form of a sclerotic endodermis already described, or of a sheath containing abundant starch grains, and termed the *starch ring*.

The former is more common in roots which do not increase in diameter, round the bundles of ferns, and is continued into the leaves of grasses, sedges, &c., where it forms a strengthening membrane.

The starch ring is found in the stem of most dicotyledons around the whole zone of the bundles, in the leaves of many monocotyledons, also in the stem of grasses.

The sclerenchyma and sclerotic cells form the strengthening apparatus of the plant. The former are united into strands, layers or sheaths traversing a whole organ, such as a leaf or stem from end to end.

Arrangement of sclerenchyma.

These bands are found in the hypoderma of hard leaves, such as those of the pine-apple, and of most *Coniferae*.

They also form a fibrous ring, in the cortical parenchyma of many plants, as in the gourd family; but the most frequent occurrence of these fibrous bands, is on the outer border of the bundle ring resting against the outermost of the vascular bundles, as in



most monocotyledonous foliage stems, and in nearly all dicotyledonous stems.

Very rarely, is a layer of sclerenchyma found on the inner side of the vascular ring, as in some plants of the pepper family, and in the *Bougainvillea*.

Thus, the bast fibres form a sheath round the vascular bundles of dicotyledons, and as they both protect the bundles and serve to strengthen them, they are frequently considered to form an integral part of the bundles themselves, the latter then being called *fibro-vascular bundles*.

This sheath of the bundle may be *closed all round*, or *partially closed*.

The first form is common in monocotyledonous stems, where each separate bundle has its own sheath.

In the leaves of many monocotyledons, such as those of the plantain and the *Phormium tenax*, we find gaps in the sclerenchymatous bundle sheath filled with thin-walled parenchyma.

In collateral bundles, as in the leaves and stem of dicotyledons, a *partial fibrous sheath* is arranged to support the phloem, either along its whole extent, or at its outer edge by a more or less strongly developed fibrous mass, often only by a small group or by single scattered fibres. As examples of trees, in which the bast fibres are highly developed, we have—

Sterculias, *Grewias*, *Urticaceae*, *Antiaris innoxia*.

In this latter tree, one of the largest in the Western Ghâts, the bast fibres are used for making sacks, a branch being cut of the required size, soaked a little, and then beaten until the phloem separates from the wood, this done, the sack formed from the bark is then turned inside out and pulled down, and the wood is sawn off, with the exception of a small piece left to form the bottom of the sack. The Garos make their mattresses of strips of a number of bast fibrous sheaths from the bark of (*Sponia orientalis*) and of *Artocarpus Chaplasha*, both belonging to the *Urticaceae*.

A partial fibrous sheath is found surrounding the pith, in certain sedges, and in *Papyrus antiquorum* of the Egyptians.

In certain cases, we find fibrous bundles isolated from the vascular bundles, as for instance, in the cortex and leaves of many *Coniferae*, where each fibre is isolated.



Short sclerenchyma is found in the bark of many dicotyledonous plants in connection with secondary growth. We have already noticed their occurrence in pears ; they are also found in hard *emergences*, such as the points of the leaves of aloes and agaves, of hollies (*Ilex*), and *Berberis*. Masses of this tissue are also found in stems and fronds of ferns.

Crystal sacs are found in primary parenchyma, in the pith of dicotyledonous wood plants, in the walls of air passages of arums, and of water plants.

Arrangement of secretory reservoirs.

Mucilage sacs. Mucilage sacs are found in the walls of the primary parenchyma of—

Malvaceæ,

Tiliaceæ,

Sterculiaceæ,

Ulmaceæ,

Cactaceæ,

Cortex of firs,

Tubers of orchids, and in many other plants.

Short sacs containing resin and gum-resin are found in—

Laurels,

Short sacs containing resin and gum Gingers,

resin. Magnolias,

Peppers,

and a few other orders, in the primary parenchyma, the foliage, pith, and especially in the cortex, as in cinnamon, also in the secondary wood of the deodar.

Tannin sacs have been already described as being most abundant in the phloem of many woody plants.

Tannin sacs.

The laticiferous tubes of most plants form a continuous system traversing the entire body of the plant.

Course of the laticiferous tubes. This of course only applies to the primary tissue. As an exception, in *Ficus elastica*, they are only found in the secondary phloem.

In the primary tissues, they are generally companions of the sieve tubes being found—

(i). In the phloem of roots. Only in Euphorbias do we find others in addition close to the epidermis.

- (ii). In stems, petioles, and main nerves. The tubes line the tissue outside the phloem, and if the phloem has a sheath of sclerenchyma, they lie outside the latter.

In lettuces and poppies, smaller tubes are found as well, inside the phloem.

- (iii). In foliar expansions, the tubes send out branches from the nerves, forcing their way in all directions between the cells of the parenchyma.

- (iv). In many milky dicotyledons, the tubes also branch into the cortex of the stem, as in *Euphorbias* and *Asclepiads*.

- (v). In many cases, thick tubes pass from the main trunks into the pith along the medullary rays.

The air-containing spaces, which are sometimes also water-

Course of the inter-cellular spaces. containing, form a connected system of communicating tubes through the plant.

Where there are stomata, this system opens first into the respiratory cavities below them, and then through the slits themselves communicate with the atmosphere.

Intercellular secretory reservoirs. The short reservoirs form oil cavities, which we see in the leaves and fruits of—

Myrtaceæ and *Aurantiaceæ*, as in lemons, the bēl, &c.

The longer cavities form passages and canals, these traverse the plant lengthwise at first as prismatic tubes, which later on have a round or elliptic section, and rarely end blind, as in many *Conifereæ*, but in most cases communicate with one another like the milk tubes branching freely at the nodes, and sending out blind or branching arms into the foliar expansions. They may be found in every form of tissue, even in the primary xylem.

In *Conifereæ*, all known species except the yew, have resin passages, or reservoirs. Starting from the leaves in those species, which have one or two medium vascular bundles, as in—

Cypresses, sequoias, junipers, thujas, *Cunninghamia* and *Podocarpus*, there is one resin passage between the bundle and the lower epidermis.

Besides this main duct, many species have other accessory passages—

At each lateral margin of the leaf, which either alone are present, as in the deodar ; or,



They may also be from one to over twenty in number, as in the leaf of *Pinus sylvestris*.

These passages, in most cases, pass through the leaves from the base towards the apex, ending blindly. They also pass downwards from the insertion of the leaf through the primary cortex, forming a ring in the latter.

In many trees, such as juniper and thuja, the passages end blindly above the junction of the leaf. In most pines and firs, however, the resin ducts descend through numerous internodes, opening into others from lower leaves, constantly widening as they proceed downwards. Most conifers have no other passages in their primary tissue.

In the root, no conifers have resin passages in their primary cortex; in the deodar, however, and some firs, there is a canal in the middle of the axial bundle.

In pines, the xylem plates in the root are in the form of a V, and the resin duct lies between their two arms.

Oil passages also occur in the roots and stems of many *Compositæ*, while passages containing etherial oils and gum-resins are found in all known *Umbelliferae*, in the root, and cortex and pith of the stem. *Asafoetida* is a gum-resin collected from the root of *Narther* and *Ferula Asafoetida*, tall umbelliferous plants from Central Asia and Afghanistan, and *Ferula galbaniflua* also yields a gum-resin termed *galbanum*. Resin passages are found in *Araliaceæ*, the ivy family, of which several species of *Panax* yield medicinal drugs.

In *Anacardiaceæ*, including the different species of *Rhus*, resin passages are found in the phloem of the stem and leaves, and frequently in the pith. This family, formerly united to *Burseraceæ*, was termed *Terebinthaceæ*, on account of the turpentine found in many species, as seen in the mango. *Rhus vernicifera* yields the lacquer of Japan, which exudes from the tree at first milky white, becoming black on exposure to the air. Many species of *Rhus* contain a poisonous sap, and cannot be even handled without producing inflammation.

In *Ailanthus glandulosa*, belonging to the *Simarubæ*, gum passages are found in the petioles and midribs of the leaflets and in the periphery of the pith of the stem, the strong odour of the leaves being due to the resin they contain.

In certain dicotyledons with an axial bundle, and a few other anomalous forms of dicotyledons, as in the *Berberis*, the primary arrangement of the bundles undergoes no further change.

Secondary growth in thickness of woody stems and roots.

A few other forms with a normal ring of bundles, such as certain species of *Ranunculus*, follow the same plan.

In a very great majority of dicotyledonous stems, on the other hand, the completion of the primary groups of tissue is followed by new elements in addition, forming the secondary growth of the stem. These changes consist chiefly in the fact that, from a zone of meristem termed the *cambium* zone, passing through the ring of bundles, new elements are added radially to the stem, which is thus augmented by a secondary growth in thickness.

Cambium.

In short-lived stems, belonging to *annual* or *biennial* plants, and generally termed *herbaceous*, this growth may soon cease.

In long-lived stems, and specially in woody plants, such as bushes, shrubs, climbers and trees, it may endure throughout the whole life of the plant, and give rise to enormous masses of secondary wood.

Annuals, such as the mustard, or the pea, are plants springing

Annuals, biennials and perennials. from seed, which flower and seed during the same year or season, and die before its close. *Biennials* are plants which, springing from seed and vegetating in one season, blossom, fructify and perish in the next season.

Their life consists of two stages, the first of *vegetation*, and the second of *fructification*. They accumulate a stock of nutritive matter, either in their root or at the base of their stem, as in the kohlrabi, the whole of which is used up in the second year of growth in the production of flower, fruit and seed.

The beet, the turnip, the parsnip and the carrot are familiar examples of *biennials*.

Perennials are plants which live, blossom, and fructify, year after year. In the case of the bracken (*Pteris aquilina*), where only the rhizome remains alive throughout the cold weather, the whole upper part of the plant dies annually. This also happens with the potato, dahlia, and many other plants, which may be termed *herbaceous perennials*.



Plants such as the teak, the vine and the rose, in which the whole portion above ground as well as that beneath it, except the foliage, the root hairs and the bark, remain persistent, during a term of years, are termed *perennial woody plants*. It is evident that at high elevations, and in latitudes where the cold in the winter is very severe, there would be a far less variety of woody plants than in the tropics, where vegetation goes on uniformly throughout the year except when interrupted by the dry season. This though it stops vegetation, only kills off superficially rooted plants.

The damp zone of the tropics with nearly uniform temperature throughout the year is naturally forest-clad, and the vigour of the vegetation, and its great variety, more marked than in other zones.

The changes due to the growth of the cambium give rise to intermediate bundles unconnected with the leaf traces, but which are simply cauline bundles and appear between the original leaf-trace ones, and are separated by secondary medullary rays from the latter, and from one another.

The cambium, in many cases, arises either simultaneously with, or previous to, the formation of these intermediate bundles, in the following way.

The delicate cells lying in radial rows on the inner border of the phloem of the leaf-trace bundles remain meristematic, and subdivide, by means of tangential walls, so that the vascular bundle grows in a radial direction; sooner, or later, the tangential divisions are also continued to a band in each medullary ray, connecting these groups one with another, so that the meristem appears in this band forming a zone within the stem, the whole of which is termed the *cambium*, that in the primary medullary rays being *interfascicular*.

- (i). In certain anomalous forms of dicotyledons, such as *Casuarina* and *Cucurbita*, and in woody *Piperaceæ* and *Berberis*, in which there are two rings of leaf trace bundles, the cambium zone is formed in a waving line passing through all the bundles.



THE ARRANGEMENT OF THE DIFFERENT FORMS OF TISSUE.

In the majority of cases, cauline intermediate bundles precede the cambium.

- (ii). (a). If we take a *Clematis* as an example, we find that in each of the broad medullary rays between two leaf trace bundles, of which there are six in the *Clematis Vitalba*, a new cauline bundle appears.

The twelve vascular bundles thus formed, increase in a radial direction, and the cambium ring appears, as already described.

Each intermediate bundle runs longitudinally through the entire internode, and is only attached to the leaf trace bundle at the node.

- (b). In other cases, several small intermediate bundles appear between every two leaf trace bundles, separated by very narrow medullary rays. These bundles unite, separating from one another, and from the leaf trace bundles, at short vertical distances, throughout an internode, and thus form a net with narrow vertical meshes filled up with the bands of parenchyma of the medullary rays. The leaf-trace bundles thus appear to coalesce with the cauline bundles, so as to form one bundle traversed with narrow radial bands of parenchyma. If we take a plant with opposite leaves, such as the teak, the rudiments of the traces of the first pair of leaves appear first, at the two opposite points, between the pith and cortex, then the traces of the next higher pair appear between them at right angles to their own direction. From the margin of these four bundles, according to their order of origin, rapidly succeeding divisions extend through the medullary rays until a closed ring of bundles has been formed.

- (c). In certain plants, the coalescence of the bundle to form a continuous ring goes so far that, all parenchymatous tissue is absorbed between the primary bundles, and the medullary rays entirely disappear.

The following plants are examples :—

Cheiranthus (wall flower), *Galium*, *Plantago*, *Rumex* (dock), *Dianthus* (pink).

No known important woody plant belongs to the third kind (c), and the second (b) includes nearly all forest trees.

According to the usual terminology, that part of the ring lying inside the cambium, *viz.*, the wood or ligneous body, may be termed the *xylem*, while everything lying outside the cambium is termed the *cortex*, the latter being sub-divided into the zone of the *liber*, or inner bark, consisting of the *phloem* and bast fibres; whilst the external cortical parenchyma lies outside this, and includes the phellogen, from which subsequent cork layers may be formed, as in *Erythrina suberosa* and *Passiflora foetens*.

The elements of the bundles in the wood may be termed *wood strands*, the liber having similar *liber strands*, these may be termed respectively xylem and phloem strands, and are separated from neighbouring strands by bands mostly composed of the parenchyma of the medullary rays.

The medullary rays formed on the first origin of the woody ring pass from the pith to the outer cortex, and are termed large medullary rays, as opposed to the *smaller rays*, formed subsequently, which do not reach the pith.

These large rays in (i) are identical with the original rays, and are, therefore, true primary medullary rays.

Under (ii) (*a* and *b*), the large medullary rays have originated from the primary ones, primary rays similar to these in *casuarina* having no existence after the completion of the ring of wood.

In (ii) (*c*) no medullary rays are found.

The cambium zone is distinguished as *fascicular* and *interfascicular* according as it borders on a medullary ray, or on a bast, or wood strand.

Growth from the cambium zone, in the direction of the radii of

The cambium, the cross section of the stem continues with pauses—

- (*a*). In the cold weather.
- (*b*). In the dry season, or,
- (*c*). In damp tropical climates, may go on uninterruptedly throughout the year.

In India, there is generally either a distinctly cold season or a season of drought, either or both of which act as a check to vegetation. Hence, we have trees which shed their leaves in the cold season, as the *tún*, the mulberry, the *semul* and many trees in the



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hill forests, such as the walnut, some maples, horse-chestnuts, &c. In northern countries, the majority of trees other than conifers shed their leaves from September to November, so that this period, known in Europe as autumn, is called by the Americans, the fall.

In the plains, and central hill districts of India, most trees shed their leaves in the hot dry season from March to July, when the monsoon commences; such are the teak, the sál, the *terminalias*, the khair (*Acacia Catechu*). The former class may be termed *cold weather leaf-shedders*, and the latter, *hot weather leaf-shedders*. The fall of the leaf corresponds to a decrease, or increase, in the rate of vegetation, according as the tree remains leafless for a certain time, as in the tún or walnut, or as in the case of the sál and the pipal puts out new foliage when it loses its old one.

Besides these deciduous trees, *which lose all their foliage within a space of twelve months*, there are many others, which retain it for about thirteen months, being never bare of leaves, as the bán oak, or the chir (*Pinus longifolia*); or for a longer period, up to four or five years, when they only lose a portion of their foliage at a time, as in the mango, *Mesua ferrea*, *Putranjiva Roxburghii*, and the fir, spruce, or yew of the hill forests. Such trees are termed *evergreen*, and besides the evergreen conifers and oaks in the hill forests of Northern India, we find numerous evergreen dicotyledons in the damp forests of the Gháts, and in the damp region of Burma, Assam, Eastern and North-Eastern Bengal, of which *Mesua ferrea* is most widely spread.

The fall of the leaf always corresponds to a change in the rate of growth of the wood, but in many evergreen trees and especially in conifers, there is a cessation of growth at some season of the year, generally in the cold season.

It is possible that a change or cessation of growth in the wood may take place more than once during the year, owing perhaps to two dry seasons, separated by an interval of moist or damp weather; or it may be due to a mechanical cause, as the destruction of the foliage by fire, or by insects. This question will be considered more fully, further on.

In every case, in which there is a sudden change in the rate of growth, we find in the transverse section of the wood a distinct zone of closer tissue than that adjacent to it.



In the chir (*Pinus longifolia*) and the tûn, where the growth stops during the cold season, these zones are formed once in each year, and are termed annual rings, so that the age of the tree may be determined, by counting the number of rings on the radius from the pith to the phloem.

In many evergreen trees, where growth continues more or less uninterruptedly throughout the year, these zones of dense tissue may be very indistinct, as in the evergreen oaks of the Himalayas, whilst in other trees in which the growth may be interrupted several times during the year, we may find two or more concentric rings in each year's growth.

Thus, in a specimen of teak wood from the Andaman Islands in the Forest School Museum, known to be $4\frac{1}{2}$ years' old, 9 rings may be counted, though teak usually forms annual rings.

In the case of most conifers, the growth of cells from the **Form of cambium cells.** cambium proceeds in a very regular manner, and we may therefore consider it as a type.

All cell division proceeds from a single annular layer of cells one row thick, which may be termed the *initial layer*.

In this, every cell divides by a tangential longitudinal wall into two new cells, one of which once more becomes an initial cell, while the other becomes a *tissue mother-cell*, and gives rise either to wood, or phloem cells.

In the quite regular case of *Pinus sylvestris*, each *tissue mother-cell* then divides once by a tangential wall, and the two resulting cells become converted into tissue elements. Even in this case, however, deviations may occur. Thus, one of the cells resulting from the tissue mother-cell may be again sub-divided; in wood, this is always the outer one; in bast, usually the inner one, rarely the outer, or each of them may divide once more.

From what we have seen it is evident that, the wood consists of radial rows of cells, whilst in the phloem there is more irregularity, as we find cambiform cells and sieve tubes alternating, and with walls directed neither radially, nor tangentially. This is partly due to the tension being greater towards the centre of the stem and less towards the outside, so that phloem cells are more irregular than wood cells. We may also note that divisions on the

wood side of the initial layer are formed far more rapidly and more abundantly than on the side of the bast, so that the xylem portion of the stem soon preponderates over the phloem.

The elements of the wood and phloem in a growing tree increase for a time in size, but after a certain period assume a constant average size.

As regards the number of elements in the tangential zone, it is evident that, it must increase as growth in thickness proceeds, or else, each element would become abnormally large. This takes place by an increase in the number of radial rows, and by radial division of the initial cells into two daughter-cells, giving rise either to new rows of ordinary tracheæ, or to new medullary rays. It will be evident, however, when we consider the minute size of the cells, and the immense number of them which go to one tangential zone, that the radial divisions in the initial layer, must take place rarely in comparison to the tangential ones, and in fact, they only appear here and there, without any order of succession.

In addition to these longitudinal divisions, transverse divisions, and also oblique ones occur, and will be described further on. Thus we see that the cambium consists of—

(i), the initial layer,

(ii), tissue mother-cells, $\begin{cases} (a), \text{ wood cells.} \\ (b), \text{ phloem cells.} \end{cases}$

The general form of the cambium cells is that of a rectangular prism, of which the radial diameter is, on the average, half as long as the tangential one, while the ends form a sharp edge lying radially, and almost horizontally.

The inclination of the lateral walls is usually confined to one side, and then directly, and alternately, to the right and left. More rarely, the two radial surfaces are inclined to one another like a roof. Hence, it follows that, elongated cambium cells, which, as meristem, are in uninterrupted contact, also form longitudinal rows, as a rule, and alternating longitudinal rows, when the two radial surfaces are inclined.

As we have mentioned before, the size of the cambium cells which varies in different species, either remains, on the average, the same throughout the whole growth in thickness, or increases continually for a series of years, until an average constant size has been



attained, the increase extending to all the diameters, so that the general form is unchanged.

In a tangential wood-section, the ends of the medullary rays appear between the long tracheæ, showing rows of small parenchymatous cells cut transversely. In oak woods, which have exceedingly large medullary rays, we find a mottled appearance on the tangential sections, due to the numerous ends of the medullary rays appearing darker than the surrounding woody tissue.

In a *radial section*, we find the parenchyma of the rays crossing the other tissues at right angles, and giving rise, where the medullary rays are large, to the so-called *silver grain*.

In a *transverse section*, the cells of the medullary rays present oblong sections at right angles to the section of the tracheæ, and in the neighbourhood of a new concentric ring, the sections of the tracheæ appear very much compressed tangentially, when compared with those of the younger wood outside.

As regards the contents of the cambium cells, we find in them

Contents of cambium cells. a densely granular protoplasm and elongated nucleus.

In the medullary rays, chlorophyll is frequently found, as in those of the vine, also in winter, small starch grains.

The cellulose walls are thin and delicate, but the tangential walls remain thin during the season of rest, whilst the radial ones become considerably thickened, this thickened mass being partially dissolved when growth commences.

The young phloem and wood cells also share in these peculiarities of growth.

Transverse divisions occur :—

- (i). Wherever we find short parenchymatous cells, not belonging to the medullary rays, and septate

Transverse divisions of wood cells.

fibrous cells, either in the secondary wood or phloem, and termed respectively wood and phloem parenchyma, this is due to transverse subdivision in cells which were originally as long as the ordinary cambium cells, such as the cambiform cells of the bast.

- (ii). Whenever a new small medullary ray arises in the midst of the wood, by the sub-division of one or more of the

ordinary cambium cells, and this may be due, either to transverse sub-division resembling what we have just described, or to the cutting off a part of the radial wall of the cambium cell, and the further sub-division of this new cell by transverse walls.

It is evident that, the secondary elements of wood and phloem are always arranged in radial rows. In the phloem, owing to the continual widening of the zone of secondary growth, there is far more room for displacement of the elements, than in the wood.

The original radial arrangement is maintained :—

- (i). When the form and length of the cambium cells undergo little or no further change.
- (ii). When, although the elements become larger than the cambium cells, they maintain a similar form.

The first case occurs almost without exception in medullary rays, in most masses of wood parenchyma, and in short tracheides.

The second case applies to the elongated elements, fibrous cells, long tracheides, &c., and even in this case, the increase in length is trifling, and confined to the long points of the elements, which penetrate between one another.

Such conditions are almost always present in the wood and phloem of conifers, and hence the ease with which coniferous wood can be carved, or otherwise worked up, by a tool, owing to its even grain, which is most marked in the pencil cedar (*Juniperus burmudiana*). In dicotyledons, we find the radial arrangement undisturbed, in the medullary rays, in the phloem, with the exception of the sieve-tubes, and in the wood parenchyma.

It is found that, many plants with leaves in whorls, such as species of horse-chestnut, &c., preserve a radial arrangement of their elements.

The radial arrangement is disturbed—

- (i). In groups of elongated elements which become greatly elongated while passing from the cambium condition to that of mature tissue, when they insert their tapering ends far between one another, and thus become curved and twisted.



- (ii). When some of the elements expand in the transverse direction, in their change to the mature condition.

The first case occurs in the bast of many dicotyledons, in the wood of many *Leguminosæ*, in *Morus alba*, *Celtis australis* and many other trees.

The second case occurs, wherever wide vessels are formed; though originally similar to other elements, the vessels resulting from the fusion of longitudinal rows of cells become expanded to many times their original size, and thus, not only displace the neighbouring elements, but frequently crush them, so that mere rudiments remain.

It is evident that, the wider these vessels become and the greater their number compared with that of the other elements, so much the more irregular will become the original radial rows of the elements.

Hence, we see that, wood with few or fine pores is more even grained, than wood with disseminated and large pores.

It is also clear that straight grained wood, such as that of conifers, will split readily in a radial direction, and hence deodar sleepers are not so good as *sāl* sleepers, as the iron bolts for fastening on the rails are likely to split them.

The large medullary rays in oak wood also cause it to split readily in a radial direction, although the wood between the rays is irregular, owing to the large vessels which it contains.

The whole of the secondary growth is continued uninterruptedly from the main axis into the lateral shoots, both of the stem and the root.

As regards the longitudinal course of the grain in wood and phloem, we sometimes find the whole stem twisted, resulting in the *torsion* common in oaks, terminalias, and in climbers. Besides this, in stems with a straight vertical growth, we find the elements obliquely arranged, this deviation from the vertical being less conspicuous in the radial direction, than in the tangential. As a rule, all elements in each concentric layer, have the same direction, the angle with the vertical varying in individual cases as much as 45° in the pomegranate, from 10° to 20° in the horse chestnut, though smaller values, usually from 4° to 5° , are more frequent.

In some trees, the inclination is invariably in one direction,



whilst in pines and firs the direction changes, becoming reversed after a number of similarly inclined layers.

In exceptional cases, as in the guaiacum wood, of South America, the grain curves backwards and forwards with short undulations in each layer of wood, often cutting the vertical at 45° , and assuming different directions in successive narrow layers. This interlacing of the elements renders it impossible to split guaiacum wood, in the radial direction, and very difficult to do so, in the tangential direction.

Owing to the toughness of guaiacum wood, it is used for pulleys, rulers, balls and any purpose where toughness is required and weight is not an objection.

We frequently find twisted fibres in *knots*, and *burrs* of woods, but this is due to injury, or to numerous *dormant buds*.

Such burrs in the walnut tree, when polished, yield beautiful panels for furniture.

In the hill maples, burrs are used for making cups, bowls, &c., by the villagers. The origin of the inclination of the wood elements (*twisted grain*) to the vertical consists probably in the fact that, after lengthening, there being no room for their upward expansion, they are forced to one side, as an oblique angle will allow for a longer element than the vertical.

A cambium ring is formed with rare exceptions, in the roots

Wood in the roots of dicotyledons and gymnosperms.

of dicotyledons and gymnosperms, and from it, a similar growth of secondary wood and phloem arises, as in the stem.

Owing, however, to the different arrangement of the primary bundles of the stem and root, the secondary growth in the latter has an entirely different origin to that of the former.

It originates in the axial bundle, beginning with tangential divisions of the larger cells bordering on the inner surface of the phloem, and proceeding from the middle of each of these groups, towards its two lateral margins, and thus, towards the outer corners of the xylem plates.

The tangential divisions eventually pass outside the xylem plates, and form a closed ring, which at first may be a narrow ellipse or a polygon, with as many blunt corners as there are xylem plates present.



As, however, the cambium produces wood unequally all round, and more abundantly when it first commences inside the phloem bundles, the latter are rapidly shifted to the outside, and the concavities of the ring become flattened, so that its transverse section soon assumes a permanent and nearly circular form. As, however, roots frequently have to pass through rocky ground and even through crevices of rocks, which they are unable to split, they are forced sometimes to assume very singular shapes moulded to the form of these crevices.

The tissues produced in roots by the cambium ring resemble those of the stem, wood and phloem bundles being produced internally and externally, and being separated from one another by bands of parenchyma or medullary rays.

It is evident that, primary medullary rays are absent in roots.

We may distinguish two main types of roots—

- (i). A main medullary ray, usually very broad, appears opposite to each xylem plate, as in *Cucurbita*, and separates the same number of main strands from one another.
- (ii). The whole periphery of the primary bundles gives rise to new bundles with small medullary rays intervening, which have no connection with the primary xylem plates.

As a rule, secondary growth takes place immediately after the primary tissues have been developed, but in adventitious roots of peppers and of the *Cereus* (a cactus), each portion of the root remains for sometime in its primary condition.

We have already described the changes in the texture of wood due to the different seasons, and have explained that, in temperate and cold climates, the wood formed at the close of the year has more compressed elements with thicker walls than that formed at its commencement, or in the height of the growing season.

The denser zone of wood may, therefore, be termed *autumn-wood*, which is readily distinguishable from the softer *spring-wood* at the inside of each concentric zone. In woods in which more than one zone is formed in the year, we may speak of those zones respectively as the denser and softer zones.

The form and dimensions of these zones have been investigated

in the case of many trees and shrubs, and has been found to vary according to age, and to the more or less favorable condition of vegetation* for the same individual, whilst under similar, or equally favorable, conditions, the average breadth varies considerably according to species.

We have compared a piece of chîr wood (*Pinus longifolia*) grown in a garden, in Dehra Dûn, with another specimen from the Himalaya, where the soil is generally poor and superficial, and being on a slope dries up quickly in the dry season.

In the former, the autumn-wood forms only one-tenth of the annual zone, which is frequently a centimetre broad, whilst in the other, the autumn-wood forms about half the annual zone, four or five of which go to a centimetre, the result being that, the hard autumn-wood is in far greater proportion to the soft spring-wood in the latter case, than in the former, so that the fast growing Dûn wood is much softer than the hill wood.

Also, in comparing teak wood from gardens in Dehra, or from plantations in Assam, with teak wood from forests of Burma, we find the number of annual zones in the former, from $\frac{1}{2}$ to $\frac{2}{3}$ of a centimetre broad, whilst in the latter, we may count as many as 10 zones per centimetre. The spring-wood, in either case, consists of a very narrow zone as compared with the autumn-wood, but is as broad in the latter case as in the former, so that the more rapidly growing plantation and garden teak contains far more autumn wood than the forest-grown specimens. At the same time, the latter is darker coloured, and more lignified, than the former, and is a much more useful wood where strength is required.

The slow growth of the indigenous Burmese teak as compared to the plantation teak is probably due to the crowding of other trees around it in the forest, as well as possibly to inferior soil, as the climate is more favorable for teak in Burma, than in Dehra Dûn.

* The main conditions of vegetation are—

1. Condition of soil ; depth, quality, inclination, &c.
2. Amount of atmospheric humidity at the various seasons.
3. Temperature ; average, annual, range, &c.
4. Aspect.
5. Interference of neighbouring plants.

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From the fact that, the spring-wood in teak is constant, whatever the breadth of the annual zone, it follows that, provided the average density of the wood is the same in two specimens, the most rapidly growing will be the heaviest, and this is the case with oaks and many other dicotyledonous trees.

In the case of conifers, however, when the autumn-wood is nearly constant, for the same species, and a more rapidly growing tree has consequently a larger proportion of spring-wood than of autumn-wood in each zone, it is evident that, provided the autumn-wood of two specimens is equally dense, the more rapid growing wood will be the lighter, and other circumstances being equal, the slower the growth of a coniferous tree, the denser is the wood.

We may compare the slow growth of the boxwood, cypress and yew with the extremely rapid growth of semal, the following countings having been made:—

Rate of growth of woody plants in diameter.

Yew, ...	...	...	35	zones to the inch.
Box, ...	...	...	20	" "
<i>Cupressus torulosa</i> ,		...	17	" "
Burma teak, ...	...	...	18	" "
Kumaon chîr, ...	...	...	10	" "
Deodar, ...	...	...	10	" "
Dehra Dûn teak, ...	...	...	4½	" "
Dehra Dûn chîr, ...	...	...	3	" "
Tûn, ...	...	...	1½	" "
Semal, ...	...	...	½	" "

In a young tree, the breadth of the annual zones increases under otherwise similar conditions for a number of years, then remains for a series of years at an average maximum, and finally decreases with age.

In counting the rings from the centre towards the cambium, on sections of tûn and deodar, we get the following results.

The rapid growth between the 9th and 10th inches of radius in the deodar is probably due to the removal of some neighbouring tree.

Inches of radius.	Tan (<i>Cedrela Toona</i>).	Deodar (<i>Cedrus Deodara</i>).
1	uncertain rings.	uncertain rings.
2	1½	7
3	1½	7
4	1	6

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Inches of radius.		Tún.		Deodar.
5	...	$1\frac{1}{8}$	rings. ...	10 rings.
6	...	$1\frac{1}{2}$	" ...	10 "
7	...	$1\frac{1}{2}$	" ...	$10\frac{1}{2}$ "
8	...	$1\frac{3}{4}$	" ...	15 "
9	...	2	" ...	15 "
10	...	2	" ...	12 "
11	...	$2\frac{1}{4}$	" ...	12 "
12	...	3	" ...	uncertain.
Totals,		<u>$18\frac{5}{8}$</u>	<u>rings. ...</u>	<u>$104\frac{1}{2}$ rings.</u>

If we add $3\frac{1}{8}$ rings to the tún, for the first inch, and $10\frac{1}{2}$ for the first inch, and 15 for the last, of the deodar, we get 22 years for one foot of radius in the tún, and 130 in the deodar, giving averages of $1\frac{5}{8}$ and $10\frac{5}{8}$ rings per inch.

In branches, the average maximum growth is generally attained in the first two years, after which, the breadth of the zones continually diminishes, until the annual rings can only be distinguished with great difficulty.

This extremely slow growth, in coniferous wood, causes the autumn zones to be so close, as to appear continuous, and the branch wood of conifers is, therefore, extremely hard and dark coloured, forming knots, and branchy trees consequently yield scantling of inferior quality. Hence, in coniferous wood, close growth causing the branches to die off, when still very young, is to be encouraged, as in this way large knots are avoided.

In a regularly developed stem, the breadth of each zone will be uniform all round, but the ring may become undulating, or excentric, owing to accelerated growth in any direction, even to such an extent, as to be wholly absent from the deficient side. The rings on the same cross sections of a stem often show remarkable differences in these respects, forming as it were a record of the history of the growth, and nutrition of the tree.

In certain woody plants, which we will refer to further on, inequality of growth is typical.

In lateral branches, and in the roots, excentric thickening is the rule.

In most dicotyledonous plants, the upper side is favoured, in most coniferous wood, however, the underside is favoured, this is



due to the erect foliage-bearing twigs of the former, and the pendulous foliage of the latter, most of the nutriment coming from the foliage, as we shall see further on. In lateral roots, the upper side is favoured, up to a certain distance from the main root, beyond which, the underside is favoured.

If we consider a forest tree, it will be found that its stem is composed of a series of hollow conical shells of wood fitting one over another.

Form of bole in isolated and closely grown trees.

- (i). In the shaft or *bole*, which is the unbranched stem from the *stock* to the *crown*, the annual growth in mass in trees *standing free* increases from above downwards. This gives the bole a conical shape.

This increase may occur, even if the zones formed above are greater than, or equal to those formed below, as the radius of each zone has to be considered, as well as its actual breadth.

In *closely grown healthy trees*, the average breadth of the zones, and of the average mass of wood formed, increases in the upward direction.

If the crown has become *stunted*, in consequence of this close planting, as is always the case with weaker individuals, which are overtopped by their more vigorous neighbours, we find a diminution in growth, from above downwards, which may extend to a complete absence of growth in the lower portion of the bole. Many species, especially of conifers, such as the silver fir, will support life in this stunted manner for many decades, and if their over-shading neighbours be removed, will frequently produce a larger crown and grow up vigorously again, though in many cases, such improvement is hopeless.

Other trees, such as the chir, cannot support the shade of neighbouring trees for more than a few years, without perishing.

- (ii). In the crown, the growth both in the stem and branches, increases in the downward direction, and resembles that of trees in the open.
- (iii). In the basal stock, we find a considerable increase in the average breadth of the ring and of the mass of the secondary growth in the outer layers, starting from the upper side of the insertion of the roots, and extending to a height varying from 3, to several metres.

At the points of insertion of vigorous lateral roots, the secondary growth is locally increased, so that the well known projections of the stock, separated by furrows, and in trees growing in tropical damp climates attaining huge dimensions, may arise in the course of a few years. A semal tree (*Bombax malabaricum*) in Coorg, measured 85 feet round the buttresses, and only 19 feet round the stem. These buttresses do not attain large dimensions in dry climates.

The forms of growth mentioned in (i) are subject to change in the same individual if planted free, or if it be near other trees. Thus some trees, such as the sál, the silver fir, the *Mesua ferrea*, grow close together, and throughout their lives always follow the rule for closely planted trees, whilst the chír becoming free in its later years by the death of all its weaker neighbours, first, follows the rule for closely planted trees, and afterwards, for trees standing free.

This may also occur in trees accidentally freed from close growth by the removal of neighbours.

It is evident that, the stem of a tree will be more conical, or cylindrical, according as law No. (i) for trees standing free prevails over the other law for closely planted trees.

Certain species of *Bombax* and of some other species have barrel shaped stems, and are evidently exceptions to the rules we have given above, though it is possible that, their abnormal shape may be due to an increase in the cortical layers, or to masses of pith.

Forms of tissue of the secondary wood.

The forms of tissue in the secondary wood are :—

Cells,

Tracheæ,

Sclerenchymatous fibres.

In certain cases, these elements are not well defined, and in the tough strong wood of trees and shrubs, all forms may be thick-walled, and sclerotic. We may take the wood of the papaya as an example of succulent soft-woods, in which this is not the case.

Tracheæ are found in secondary wood, either as vessels, or as tracheides; of the vessels found, those reticulately thickened principally occur in soft-wood, such as that of the papaya, and in many fleshy roots,



also in *Cactaceæ*. Ordinary woody dicotyledons have pitted vessels in their secondary wood, which may contain a fine spiral fibre; the pits are bordered and correspond to one another where the surface of the vessel borders on another vessel or on tracheides. Where a vessel borders on some element other than a trachea, various conditions occur.

Tracheides are the only tracheæ in the wood of *Coniferæ* and *Winterææ*. In other natural orders of woody plants they accompany vessels.

In the *Coniferæ*, they have bordered pits, whilst in the *Taxineæ* they have spirals as well.

As regards the length of the tracheides, some of them become very elongated, and resemble sclerenchymatous fibres, from which they differ only in the markings on their walls. These fibres may be twice to three times as long as ordinary tracheides.

Sclerenchymatous wood fibres may be distinguished from tracheides, by the structure of their walls; they have never spiral threads lining their cavity, and their pits are few in number and invariably slit-shaped, and usually not bordered; their walls are as a rule lignified and very thick compared to their cavity. One of the thickening layers, generally the innermost, may be gelatinous.

The following table shows the comparative lengths of tracheides and fibres :—

				<i>Hundredths of a millimetre.</i>	
				<i>Tracheides.</i>	<i>Fibres.</i>
<i>Celtis Australis</i>,	...	...	...	26	87
Horse-chestnut,	...	...	...	26	43

The contents of the fibres may be shrivelled remains of the protoplasm, but as a rule, nothing but air or water is present.

Cells in the secondary wood may be distinguished according to their form, as follows :—

Cells.
Fibrous cells.

Short cells.

The former resemble the woody fibres more or less closely in form. They are generally without any transverse divisions, but these may occur, when they are termed *septate fibrous cells*.

The cell nature in them either persists permanently or disappears

slowly, and in the latter case they may be termed *intermediate cells*.

The former, which are the true fibrous cells, almost always contain starch.

The intermediate cells agree with the short-celled parenchyma in all their properties except their shape.

Short cells may be found either in the bundles, where they form **Short cells.** *wood parenchyma*, or in the medullary

rays.

In the case of the papaya, the semal and other loose textured woods, and in many roots, most of the tissue is composed of wood parenchyma, which arises from the ordinary cambium cells by transverse sub-divisions.

We thus find these cells arranged in rows, each row corresponding to an original cambium cell.

The nature of the cell contents is that characterised by the term parenchyma. In most hard woods, the starch grains stored up periodically during the season of rest form the chief contents. Chlorophyll and tannin are also sometimes found. It is thus evident that, wood containing much parenchyma, such as semal wood, is more readily attacked by insects and fungi, if felled during a season of rest.

As regards the walls of these cells, they are generally thinner than those of the other elements, and are destitute of spiral and annular fibres.

The parenchyma of the medullary rays consists, in most secondary woods, of cells having the same properties as the wood parenchyma, without exactly resembling it.

In woods, which are not fleshy and succulent, unlike those of the papaya, cactus, &c., the medullary ray cells-walls are lignified, except in many climbing plants, in which the medullary rays remain unligified and yield to pressure and extension.

The form of medullary ray cells may be roughly compared to a brick, they are either *procumbent*, their greatest diameter being horizontal and radial, which is by far the most frequent case; or *upright*, the greatest diameter being vertical, as in certain species of *Asclepias* and in *Nerium*.



In wood, parenchymatous cells are always accompanied by narrow air spaces, and in particular cases **Intercellular spaces in secondary wood.** to which we shall refer below, they surround wide passages containing secretions.

Other forms of tissue are of smaller importance, the most widely distributed being crystal sacs, which are only found in the parenchyma, as in many Leguminosæ, of which the red sanders (*Pterocarpus santalinus*) is an example.

Milk ducts are found in the wood of the papaya, which is chiefly parenchymatous. In other plants containing latex, only those branches running from the cortex to the pith pass through the secondary wood.

These tubes, running from the pith to the bark, must have existed before secondary wood has been formed, and have become enclosed in it.

In nearly all known dicotyledonous woods, every zone possesses a large number of medullary rays, new **Medullary rays.** secondary ones continually arising, as the ligneous mass grows in thickness, their number continually increasing with that of the successive layers, and therefore with the age of the tree.

Where the increase in number of the medullary rays is slight, the original ones become wider, as they approach the phloem, as in certain species of oak.

The case of wood without medullary rays, and in which the ligneous bundles form a cylinder round the pith, has been already referred to, and is also found in certain fleshy roots.

The *length* of a ray is measured on a transverse section, those rays which run from the pith to the cortical parenchyma being termed *long rays*, whilst others which originate in the midst of the wood and generally at a concentric ring, are termed *intermediate* or *short rays*.

The *breadth* of a ray may be measured on a transverse section, but would be more correctly measured on a tangential one, in which the rays appear lens-shaped; the short diameter of each lens being the breadth, and the long diameter the *height*. The height may also be measured on a radial section, provided the section passes through the midst of the ray.

The number of medullary rays as seen in a transverse section is in inverse proportion to their breadth and length.

Professor Nordlinger has counted the number of rays in different woods, and he finds for a breadth of 5 *m.m.*

				Rays.
Clematis,	...	...	...	10
Maples,	...	...	...	33—53
Firs,	...	...	...	37—44
Pomegranate,	...	...	...	105
Rhododendron maximum,	...	...	...	140

The average breadth of a ray varies in different species from 1 *m.m.* in the grey oak (*Quercus incana*) to .015 *m.m.* in the horse-chestnut, the box, juniper, &c.; very broad rays occur in the oaks, and in *Alnus nepalensis*.

As regards the height of the rays; in wood without intermediate bundles, or in clematis, with one intermediate bundle to each primary one, the rays are equal in height to an internode, that is, from a hundred to two hundred millimetres. In the smallest rays of firs which are only one or two cells high, it is about 0.025 *m.m.*

A comparison between two medullary rays may be more readily made by counting the number of layers of cells composing the medullary ray in breadth and height.

Rays under .025 *m.m.* are generally one cell broad, and are thus *uniseriate*, as seen tangentially in almost all conifers, whilst broader rays are *multi-seriate*; similar rules hold good for their heights, where the number of cells may vary from very high figures down to one or two.

Some woods have two sizes of medullary rays, as in firs, where the broad rays have a resin canal in their midst, which are not found in the smaller rays. Oaks and casuarinas have broad high *multi-seriate* rays with numerous low *uniseriate* ones between them.

Medullary rays generally exactly fill the meshes between the ligneous bundles that come round them, an exception being made by the *medullary spots*, we shall describe below. Medullary rays in most cases consist of parenchyma, whilst in *Coniferae* nearly all parenchyma found in the wood is confined to the medullary rays. Even in the papaya the greater part of the wood is formed by large-celled broad and high medullary rays.



It is very rare to find wood in which the zones are even approximately concentric, but in such cases the medullary rays run fairly straight from the pith to the bark, in other cases, the rays generally bend so as to cut the annual rings nearly at right angles, and are only straight at the broadest and narrowest portions of the wood.

Exceptions rarely occur in which the structure of the medullary rays is not parenchymatous; amongst the firs, pines, and in the cedar, we find two kinds of elements in the medullary ray, *viz.*, parenchymatous cells and tracheides.

In all pines, and many firs there are two kinds of medullary rays.

Larger rays containing a horizontal resin canal running into the phloem, and not communicating with the other resin canals of the wood or phloem.

Smaller uniseriate rays, usually from one to twelve cells in height, and destitute of resin canals.

In the deodar, only the second kind of rays are present. The larger rays mentioned above consist of elongated procumbent cells, whilst the latter kind are fibrous and not pitted as in the former case. These pitted cells are really tracheides. In a few other exceptional cases, the medullary rays are formed of elongated fibrous cells.

In many woods, accumulation of cells occur, appearing in cross section as elongated spots frequently in the middle of an annual zone, and extending longitudinally from a few millimetres to several feet, and not unfrequently crossing one another. They are rendered conspicuous to the naked eye by their brown colouring, and consist of irregular cells with thick pitted walls containing starch, tannin, &c.

As the medullary rays pass through these spots, their cells become broader, gradually coalescing with those of the spots, and from outside the latter, new medullary rays start, which may be quite independent from those coming from within.

They are common in *Rosaceæ*, as in species of *Pyrus* and *Prunus*, and also occur in semal, alders, poplars, willows and in many *Coniferae*. They are said to be the starting point of the formation of cherry gum, *Cerasin*, which is soluble in hot water, as distinguished from *Arabin*, or gum arabic, soluble in cold water.

In certain trees we find local swelling of the medullary rays, due to increase in breadth and number of cells, which is a less decided form of medullary spot found in certain conifers.

The structure of the ligneous bundle within an annual zone
The ligneous bundles. differs according to—

- (i), the presence or absence of any particular form of tissue ;
- (ii), distribution of the tissues present ;
- (iii), the form and structure of each element ;
- (iv), differences in the forms of tissues in the spring and autumn wood, of softer and denser zones ;
- (v), general grouping of all the elements.

In some few woods, we have only one form of tissue, to the exclusion of all the rest, and its elements are then tracheides, which apart from their differences in the spring and autumn wood are everywhere of the same structure.

In such woods, there would be no *medullary spots*, the parenchyma being only found in the medullary rays which are inserted everywhere in great numbers between the bundles.

Amongst dicotyledonous woods the *Winteræ*, a sub-order of *Magnoliaceæ*, are of this class.

Among *Coniferæ*, the yew is the only species with a simple structure, and even here medullary spots are occasionally found.

In other *Coniferæ*, we find bundle parenchyma forming medullary spots in vertical rows amongst the tracheides, and sometimes, as in many firs and pines, coating the resin ducts.

Tracheides are arranged in radial rows, and are quadrangular in cross section when neighbouring rows are opposite, and hexagonal or pentagonal when they are alternate. Their radial surfaces have large bordered pits, which are only found *tangentially* in the autumn wood. In the yew, we find spiral threads as well as bordered pits.

The resin ducts run longitudinally, and are sometimes numerous in the autumn wood.

They are large and numerous in the chir, where they are apparently evenly distributed throughout the wood.

They are less numerous in the kail (*Pinus excelsa*), and are small and few in the spruce, and are not found in the European silver fir (*Abies pectinata*).



Medullary resin ducts are found in all these species, but are most conspicuous in the spruce, so that if a spruce be barked standing, the barked wood becomes covered with resin from the numerous medullary resin ducts cut across in the removal of the bark.

This is not the case with the silver fir (*Abies Pindrau*).

It is evident that the only Himalayan conifer which could yield any considerable quantity of resin is *Pinus longifolia*; *Pinus Khasia* of Assam, and *Pinus Merkusii*, which grows at comparative low elevations in Tenasserim, might also yield resin profitably.

When tapped experimentally in the rough country way for resin, the chir has yielded 3 seers in one year per tree of crude resin.

In the deodar and in the cypress and juniper as well, instead of ducts, we have cells or small sacs containing resin, and deodar wood can be readily distinguished from pine wood even when weather-worn by the small perforations due to the resin ducts, which are found throughout the wood. This characteristic* is very useful for detecting the difference between deodar and pine logs and scantlings brought down by a river.

The ligneous bundles in dicotyledonous wood with very few exceptions, always contain vessels, so do the *Gnetaceæ*, amongst conifers. They contain as well at least one of the elements given below, of which bundle parenchyma and intermediate fibres are usually present together.

Ligneous bundles in dicotyledonous wood.

These elements are :—

Tracheides.

Bundle parenchyma (intermediate fibres).

Fibrous cells.

Woody fibres.

Septate fibrous cells.

Although no strict law holds good for the distribution of the tissues in wood containing vessels, still certain general rules may be given.

Vessels occur in all the layers of the annual zone, but are usually more frequent in the internal than in the external portion, as in teak and tûn.

Vessels.

* Perforations found on some transverse sections of deodar wood, but in concentric lines and confined to certain zones of the wood, are apparently resin ducts.

It is not uncommon, however, for the vessels to be equally numerous throughout the zone, as in the *sál*, the maple, the mulberry, and the walnut.

In *Avicennia*, a wood of the tidal forests of India, the vessels are more numerous than all the rest of the elements put together.

The vessels as a rule lie in small groups surrounded by other tissue, and are either arranged in radial bands, as in oaks, or in concentric zones, as in teak and *tún*.

Vessels are usually larger in the inner part of the annual zone, diminishing gradually in size towards the autumn wood, as in teak, or they may be of uniform size throughout, as in the *sál*, the semal and many other woods.

The sections of vessels on a transverse section of wood are termed pores, and these are classed as follows by Mr. Gamble* :—

Extremely small, as in *Buxus sempervirens*.

Very small, „ *Acer pictum*, (*Holarrhena antidy-senterica*).

Small, „ *Adina cordifolia*.

Moderate sized, „ *Bassia latifolia*.

Large, „ *Albizia Lebbek*.

Very large, „ *Erythrina suberosa*, (*Bombax malabaricum*).

Extremely large, „ *Bauhinia VahlII*, and many climbers.

The pores may be also sub-divided longitudinally, as in the semal, or they may each be surrounded by parenchyma, as in the pyinkado (*Xylia dolabriformis*).

In parenchymatous wood, such as the semal or the papaya, the bundle parenchyma forms the main mass, in which the vessels and other elements are inserted in groups.

In more solid woods, the bundle parenchyma has a regular relation to the vessels.

It either surrounds each vessel or each group of vessels, *e.g.*, in the pyinkado. Or the parenchyma may form tangential bands, passing between the rows of vessels, as in the spring wood of the

* Manual of Indian Timbers, page 11, those named in parentheses are not given as examples by Mr. Gamble.



teak and the autumn wood of the mulberry and of the farash (*Tamarix articulata*).

In the casuarina, and in different species of *Ficus*, each annual zone has several concentric bands of parenchyma, which gives one the idea of several concentric rings in each zone.

The soft parenchymatous nature of *Ficus* wood is evidently of great advantage to it in its epiphytic growth, in which the numerous aerial roots and stems form a cylinder by uniting their living tissues, so that in time they completely surround the tree on which the *ficus* is growing.

In certain roots, as that of the *Oppopanax*, the parenchyma in the roots is full of secretory passages for gum resin.

Intermediate fibres always accompany, or represent bundle parenchyma, and are therefore found under the same circumstances as it is.

Intermediate fibres.

Woody fibres and fibrous cells may occur in all layers of the annual zone, but are most abundant in the central portion, in the case of hard woods.

Woody fibres and fibrous cells.

The whole fundamental mass of wood may be composed of tracheides and vessels, as in *Pomaceæ*, which have remarkably even-grained wood suitable for carving and for drawing instruments.

Tracheides.

In other woods, they occur in conjunction with fibres, and are thus near the vessels. If two sorts of vessels are present, tracheides accompany the smaller one. Tracheides are in many cases most abundant in the autumn wood.

We have already referred to the tangential flattening of the elements in the autumn wood, the line of separation between which and the frequently largely expanded elements of the early spring wood of the succeeding year gives rise to an *annual ring*. This flattening is due to increasing cortical pressure. An increase in the thickening of the wall and sometimes further changes in the structure also distinguish the autumn from the spring wood.

Between the relatively narrow zones of spring and autumn wood we have the normal *summer wood* of temperate countries, and it is probable that the production of new foliage and shoots, and

frequently of inflorescence in the spring, may use up much reserve material, which in the summer goes to the more complete lignifying of the tissues.

In certain species of birch, willow, poplar and alder we find thin-walled tracheides in the autumn wood, and parenchyma in that of mulberry, ash, *Ailanthus* and a few others.

The changes which occur, and especially the shortening of the radial diameter in the autumn wood, affect the medullary rays as well as the ligneous bundles, and may happen suddenly or gradually for different species or for the same species under different circumstances.

The difference between spring and autumn wood is most clearly visible in coniferous wood, the bulk of which consists only of tracheides and medullary rays. In the rays, the radial shortening is inconspicuous, but the tracheides, which are wide at the spring limit of the annual layer, are much flattened in the autumn wood, whilst the absolute thickness of their walls is increased, and pits appear on their tangential walls, which in the spring wood are only found on their radial walls.

In dicotyledonous woods the shortening of the radial diameter is also general in the autumn wood, though the shortening may occur in a slight degree. Thickening of the wall may also take place at the same time.

Vessels in dicotyledonous wood frequently decrease in size from the spring to the autumn limit of the zone without being flattened conspicuously. A decrease in their number is also not unfrequent.

Both these differences may appear gradually, as in willows and the box. Or, the first spring portion of the zone, as in teak and tûn, may be rendered highly porous by numerous wide vessels succeeded by less numerous and narrow ones, and in this case the annual rings are very distinct.

In other woods, as in the sál, where pores nearly uniform in size are uniformly distributed throughout the wood, the limit of the annual ring may be very undecided if not imperceptible.

The question as to whether in damp tropical climates more than one ring may be formed during the year has not yet been tested except in one or two instances, but in many woods, as in the sál, it is impossible to ascertain the exact age of a tree by counting the



rings on a cross section of the wood, owing to their indistinctness and to their coalescing in certain points.

This is accounted for by different tensions of the bark, and variable supplies of sap and other nutriment to the cambium zone at different periods of the year.

As the different texture of the autumn wood to that of the spring wood depends partly on the pressure of the bark, and it is quite possible that an increased pressure of the latter may take place more than once during the year, we should thus have as many rings in an annual zone of wood as there are periods of increased pressure in the bark.

When forest fires annually destroy the foliage, as in unprotected *sûl* forest, we have a sudden demand on the reserve material to produce new foliage, and it is probable that a ring of softer tissue would result in the wood.

In the pipal and other figs, we have *spurious annual rings* formed by numerous zones of parenchyma between the other tissues.

The first annual zone of every wood has necessarily a different **Structure of first annual zone.** structure to that of the succeeding one owing to the group of spiral and other vessels and tracheides corresponding to the primary vascular bundles. These usually project into the pith together with its endodermis, and may be distinguished as the *medullary sheath*.

In coniferous wood this is the only part of the wood where vessels are found.

In roots the internal limit of the first annual ring has a different structure, there being at least one layer of cells between the axial bundle and the secondary wood.

In many woody plants we find a physical difference in certain **Sap-wood and heart-wood.** zones of the wood by which the softer and generally the lighter coloured outer zone is distinguished from the heavier and denser and frequently darker coloured inner zone. The former is termed *sap-wood*, or *alburnum*, and the latter heart-wood, or *duramen*.

Sap-wood has been completely developed *structurally* from the cambium and has a light whitish or yellowish wood colour.

In many trees, as in the semal, maples, the box and firs, the *alburnum* condition undergoes no change as regards the outward

appearance and the coarser physical characteristic properties of the wood, these are termed *alburnum* or *soft-wooded* trees. In other woods changes of the chemical and physical characters take place sooner or later in older parts of the wood. These changes represent the beginning of a process of degradation which ends in decomposition, and as they proceed, the wood ceases to be available for its original physiological work except for conveying water and soluble inorganic matter from the ground to the crown, and for the purely mechanical function of affording support to the crown of the tree in those woods which become harder.

A darker colour appears varying in different kinds of wood from the deep black of ebony to dark green in guaiacum wood, and red and violet in the *Pterocarpus santalinus* (red sanders), *Pterocarpus indicus* (padouk), *Pterocarpus Marsupium*, *Hæmatoxylon campechianum*, the log wood of America.

With these changes the specific weight and hardness also increase and the contained water is diminished, whilst hardly any reserve material remains in the cavities of the elements of the medullary rays, or at any rate owing to the lignification of the latter no fresh reserve material finds its way into them.*

In these cases the technical value is enhanced, and the wood becomes far stronger and less liable to decay or to attacks of insects than the sap-wood.

In spite of the great durability of heart-wood in timber properly dried and protected from atmospheric moisture, yet in a living tree we must consider its formation as a commencement of decomposition. In certain willows and in the spruce a dark heart-wood is found, which has neither a higher specific gravity, nor is harder or more durable than the sap-wood, but has a tendency to rapid decomposition.

The complete disorganization of the centre of an old tree, as in willows, which invariably occurs, if it be allowed to stand long

* Nördlinger states that there is another uncolored zone of wood in certain trees intermediate to the sap-wood and heart-wood, which he terms *Reifholz*, semi-heart-wood and he distinguishes four categories of woods—

- (i). *Soft-woods*, containing only sap-wood, as birches.
- (ii). *Semi-hard-woods*, with sap-wood and semi-heart-wood, as the Scotch fir.
- (iii). *Hard-woods*—(a), of sap-wood, and heart-wood, as oaks ;
 (b), of sap-wood, semi-heart-wood and heart-wood, as elms.



enough, and is not removed by storms, is simply a continuation of the process of decomposition in the tissues of the wood which commenced in the heart-wood, the sap-wood being the last to decay in the living tree.

In the change from sap-wood to heart-wood we find no alteration in the structure or thickness of the cell-walls, but merely changes in their chemical composition or material properties, and in the contents of the cavities. The tissues are permeated by various organic bodies, resins, &c., which often fill up the cell cavities completely, as well as any cracks or crevices that may be present. The colours of the heart-wood are then of these permeating substances.

Amongst them are the colouring matters of dye-woods, and the infiltrations of resin in the wood of many conifers and of the *sál*, the *pyinkado*, &c.

The wood oils found in various species of *Dipterocarpus*, and also the oil of sandal, are also principally confined to the heart-wood.

The infiltrating substances appear as deposits inside the vessels and cell cavities, they must, therefore, be first in a fluid form, becoming subsequently hardened. In ebony, a species of heart-wood which, however, does not always appear in the centre of the tree, and in *Diospyros Kurzii* is in variable bands in the whitish sap-wood, the cell cavity is completely filled with these accumulations, so that the structure of the wood becomes scarcely discernable under the microscope. The black wood of *Diospyros Melanoxyylon*, from which the Bombay ebony is taken, is called *Abnus* in vernacular. Its weight per cubic foot is 75—80 lbs., as compared with 49—50 lbs. per cubic foot of the sap-wood, the extra weight being due to the accumulations of foreign substances. The best Indian ebony is the produce of *Diospyros Ebenum* in Southern India and Ceylon.

D. quersita yields the calamander wood, which is in alternate bands of brown and black, and largely used for cabinet work. As a last stage in the changes described, we find the normal membranes in certain woods becoming transformed into masses of resin, mucilage, or gum, as in certain species of pine and in cherry-gum yielding trees, in which the walls of the elements become gradually thinner until they are undistinguishable in the mass of

the gum, or resin. As an example of this conversion, a tree of *Spondias mangifera* close to the Dehra Dún School compound, became covered with huge masses of gum which exuded from the bark, and hung from the branches in lengths of several feet.

In addition to these organized infiltrating substances, considerable accumulations of silica are also found, especially in teak wood, where they fill up the cavities of the cells and vessels. Calcium carbonate is also found in khair and other wood in the same way.

Another characteristic of the heart-wood is the complete disappearance of starch, but this takes place after a more or less prolonged period in different trees, starch having been traced in oak trees up to 60 years' zones and then ceasing entirely. It is chiefly due to the presence of starch and other reserve material, in sap-wood, that it is so liable to decay, and to the attack of insects. Hence, if we are obliged to use sap-wood for rafters, &c., we should choose the time for felling such wood, when there is the least reserve material in its tissues, *i. e.*, at the height of the season of growth.

The heart-wood is frequently not concentric with the annual rings, so that it may form over a greater number of rings on one side of a tree than the other. In a specimen of *Boswellia serrata* (salai), we find a very broad sap-wood with distinct concentric rings surrounding a heart-wood with another set of rings which are inclined at an angle to the former set. For trees growing under similar circumstances, we find that after a certain number of years the breadth of the sap-wood remains constant, being generally a few inches broad, hence the proportion of the heart-wood to the whole mass of the wood must increase with the age of the tree until natural decay of its centre takes place. As the sap-wood is of little or no value, but rather a great source of weakness, it is, therefore, advantageous to allow the trees to attain large dimensions, before they are felled.

It is found by experience that tapping pine trees for resin renders the wood much more resinous, and also by reducing the rate of growth causes consecutive autumn zones to approach very near to one another. Thus, pine wood, in consequence of the injuries received when tapped for resin, becomes harder, darker coloured, heavier and more inflammable than ordinary pine wood. Owing to the action of gravity, we find more resin in the lower portion

of the stem and in roots, and strips from the stumps of felled conifers are largely used in the hills for torches. It is possible that the formation of ebony may also be accelerated by injuries to the tree; its presence is detected by boring, and in many trees it never appears at all. Heart-wood appears at different ages in different trees, being very early in the mulberry and walnut.

There is a considerable difference in the wood of trees growing vigorously compared with that of feebly developed trees, as for instance those grown in a dense unthinned forest.

In coniferous wood when growing feebly, the outer zone with narrow cell cavities and thick walls is less sharply marked off from the inner zone, than in more vigorous specimens.

In slow growing dicotyledonous wood the middle portion of the zone becomes reduced, so that in trees like the *tún*, which have large vessels in the spring wood, we find consecutively narrow zones composed of very porous layers of thin vessels followed by narrow dense layers of autumn wood.

The wood of roots is generally less dense, and formed of larger elements than that of stems, an exception occurring in the main roots of conifers, which are heavily charged with resin, and are used for torches in the Hills. So is the wood of branches enclosed in the stem, which is exceedingly dense and hard, forming the well known knots or plugs in planks of pine and fir.

The cambium ring of dicotyledons and gymnosperms produces on its outside secondary layers of phloem, which are added to the original bast zone

Phloem.

of the stem. A similar process takes place in the root.

The external limit of the phloem is formed by primary phloem groups and medullary rays which lie between them, and it is sharply marked off from the tissue of the cortical parenchyma, especially where a sheath of bast fibres surrounds the primary phloem.

A further modification in the growth of the phloem as compared with that of the wood, results in that after its first formation its surface must be constantly stretched, as the cylinder of wood which it encloses expands. Phloem consists of strands of various elements separated from one another by the large and small medullary rays which are continuous from the wood through the cambium.

Sieve tubes and parenchyma are characteristic of the secondary

phloem of dicotyledons and gymnosperms, they may be accompanied by crystal-sacs, bast fibres, and by stone-cells, and finally laticiferous ducts and secretory reservoirs are found in the phloem of certain species.

All these elements, except the sclerenchymatous ones, possess delicate non-lignified soft walls, and are originally narrow, and in most cases resemble the cambium cells from which they are derived. For these reasons, for a long time, the structure of the bast was extremely obscured, and is not yet satisfactorily known.

In preparing fibres for the textile arts, the phloem is beaten, after macerating the soft tissues in water; in this way the hard sclerenchymatous fibres which alone are useful, are separated from the softer elements.

The medullary rays inside the phloem consist of parenchyma and expand outwardly in breadth, only the long ones reaching as far as the cortical parenchyma, and the shorter ones terminating within the phloem.

Sieve tubes accompanied by parenchyma are always found in the phloem of dicotyledons. In cypresses and yews, the rows of elements in the phloem are regular both radially and tangentially. Every fourth row consists of bast fibres, whilst of the remaining three, the middle one is parenchymatous, and the outer and inner ones form interrupted layers of sieve tubes.

In most dicotyledonous woods the parenchymatous cells resemble the cambiform cells described in the primary tissue are smaller than the sieve tubes, which are very prominent in the vine. In roots we find a similar structure.

In plants with laticiferous tubes, large non-articulated tubes accompany the sieve tubes, as in *Ficus* and *Morus*.

In papayas the milk tubes are less developed in the phloem than in the wood.

It is quite exceptional to find any resin ducts in secondary phloem of conifers, except the blind ends of the medullary resin ducts. In this way a good deal of resin may occur in the phloem of the spruce fir.

Sacs containing crystals are common in phloem.

In addition to our previous description of these fibres, it may



here be noticed that an unligified membrane of cellulose often surrounds the more or less lignified thick membrane of the fibres.

Bast fibres are entirely absent in many plants, as in *Ribes*, *Berberis vulgaris* and others generally herbaceous. In the majority of cases however they occur—

(i). At the outer limit of the primary bundles and not in the secondary phloem, as in the birch, alder, mistleto, pomegranate, firs, oleander, &c.

(ii). Both in the limit above mentioned and in the secondary phloem, and this is most frequent in woody plants.

Fibres are very rarely found in the medullary rays, but occur in the linden* (*Tilia europea*).

Under (ii) we have the following arrangements of bast fibres :—

(a). Concentric layers or rows of fibres alternating with layers of soft phloem, and forming annular zones round the stem, interrupted by the medullary rays. This is very common in the cypress and the yew, where every fourth row in the phloem consists of fibres.

(b). The concentric zones of fibres alternating with soft phloem are here and there regularly arranged, but are generally irregular, and this form is characteristic of the bast of very many dicotyledonous trees, as the oak, pear, walnut, elm, olive and poplar.

(c). In many other dicotyledons, the fibres are scattered throughout the soft phloem singly, or in small groups, though sometimes very numerous, as in *Ficus elastica*, *Morus* and *Celtis*.

Short sclerenchymatous elements or stone cells will be referred to hereafter.

Crystal sacs.

Crystal sacs frequently, though not universally, form a constituent of the sec-

ondary phloem.

In trees with a persistent cortex, as for example the silver fir,

Subsequent growth of phloem.

the difference between the growth of the wood and the phloem is very considerable,

* This name is adopted to avoid confusion with that of the lime (*Citrus medica*).

the absolute thickness of the phloem being very small, frequently scarcely more than 1 *m.m.* thick in trees of large diameter.

Woody plants which periodically throw off their cortex show a more vigorous production of phloem, especially in those like the vine, which annually throw off and renew their entire phloem zone. The rings formed in the phloem are readily seen when fibrous zones alternate with soft phloem, but are not found to correspond with the age of the tree, often only 20 zones corresponding to a century of growth.

The vine generally forms two fibrous zones alternating with soft phloem in its first year, and from three to five zones each in later years.

In most dicotyledons and gymnosperms, the mass of secondary wood and phloem is bounded on the outside by the primary phloem and the external cortex. It is clear that the surrounding tissue may undergo changes, in consequence of the secondary growth which may also affect the structure of the pith.

Secondary changes, outside the thickening zone.

When a tough solid bark restrains the expansion from the cambium, the original circular pith becomes reduced in size, so that in the case of an *Aristolochia* its diameter in one direction becomes $\frac{1}{10}$ th of its other diameter.

In the *Astragalus gummifera* of Persia, yielding gum tragacanth, the pith becomes disorganized, its structure disappearing, and is changed into mucilage.

This mucilage is capable of swelling considerably, but is kept inside the healthy plant by the pressure of the surrounding tissues.

After any injury to these, the mucilage exudes from the cracks in the bark in the form of strings, which form the *gum tragacanth* of commerce.

In old woody stems the starch gradually disappears from the pith, as well as from the medullary rays of the heart-wood, and the pith may become charged with resin, and other substances, in the same way, as the heart-wood.

Changes in the cortex.

Changes in the cortex due to the growth of the stem in thickness may be classified as follows :—



- (i). Growth of existing tissue elements and new formation of equivalent ones.
- (ii). Compression, displacement and destruction of existing tissues.
- (iii). New formation of non-equivalent forms of tissue, such as cork, from existing ones.

The process indicated by (i) only affects the epidermis and parenchyma.

In most cases in which secondary growth is vigorous the epidermis is destroyed at an early period and replaced by cork and bark.

In certain stems however, with a weak growth in thickness, the epidermis may persist for a considerable period. This happens with many herbaceous plants and in woody plants with a smooth green cortical surface, as long as the latter is present.

This condition of the surface depends on the persistency of the epidermis, through the transparent cells of which the chlorophyll parenchyma below can be seen. As examples we may mention—mistleto (*Viscum album*), species of holly, jasmine and the camphor tree.

In *ACER STRIATUM*, the epidermis remains alive on stems a foot thick for 40 years and more.

The long lived epidermis of these woody plants has generally strongly cuticularised outer walls excreting sometimes large amounts of wax, and the change the cells undergo during the growth of the epidermis is generally confined to a thickening of the cuticle, and also to a radial division of their walls, to allow for the increased girth of the plant, the epidermal cells continuing of the same average size throughout or only undergoing inconsiderable changes. The cells of the epidermis of *Acer striatum* when it is 200 m.m. thick are scarcely twice as broad as those on the shoot one year old and 5 m.m. in diameter.

Considering the bark of a tree to be composed of the phloem, the primary cortical parenchyma and the medullary rays in the phloem, we have three kinds of parenchyma to be considered :—

- (i). Phloem medullary rays.
- (ii). Soft phloem.

(iii). Primary cortical parenchyma.

Each of these layers may continue to grow until it is cut off from the nourishment supplied by the stem, by the formation of an inner zone of cork.

As regards the phloem parenchyma, the cells increase uniformly and gradually in breadth from within outwards, so that the tissues which do not grow with them become more and more removed from one another by the growth of the intervening parenchyma the further they are from the cambium. This regular growth of the parenchyma takes place in willows, in the pear and horse-chestnut.

In other cases there is scarcely any growth except in the medullary rays, which broaden out in the bark, and in such stems, the bast fibres preserve their original arrangement. This is the case in the linden tree, in *Hibiscus*, and many other species.

When the parenchyma in the cortex grows, increase in the tangential diameter is most conspicuous, and in proportion to this increase in breadth radial division takes place, and increases the number of cells in each tangential row.

As regards the structure of the cell-walls, and the contents of the cells, we find the quantity of starch varying from time to time, in some cases throughout the life of the plant, in others only for a time.

The latter case occurs when *sclerosis* of the cell-wall takes place.

In this case certain cells or groups of cells in the parenchyma become sclerotic, either maintaining their original form as *stone sclerenchyma*, or undergoing considerable changes in shape and size, when they may be termed *many armed stone sclerenchyma*.

These stony formations are generally first formed at the limit between the phloem and primary cortical parenchyma.

We are now come to such a stage that the term cortical parenchyma is no longer applicable to the outer cortex, which may be considered to include all the tissues of the bark outside the phloem, and this latter may also be termed the inner cortex. It is evident that, as the outer cortex is formed from the primary parenchyma surrounding the leaf trace bundles in a young shoot, that its subsequent growth must have been very considerable, especially



by radial sub-division, to enable it still to surround the rapidly growing cylinder formed by the growth from the cambium zone.

This growth in many cases, as in the *Albizzia stipulata*, is so rapid, that the outer cortex may increase from a circumference of a few *m.m.* to that of several *c.m.* in one, or two years. The increase in thickness of the cortex is also frequently very considerable.

In numerous woody plants we find a ring of stone cells with scattered fibres or fibrous bundles intervening, which are themselves the expanded bast fibres from the primary bundles.

This ring might be either completely closed at an early period, as in certain species of cinnamon, or else remains locally interrupted by a thin wall of parenchyma for years, as in the case of the birch.

Besides the birch, we find this ring in oaks, walnuts, laurels, &c.

In the *bán* and several other species of oak, this ring sends out protrusions opposite to each medullary ray, projecting inwards as far as the cambium, and sometimes even penetrating the wood, so that the cambium is deeply indented at the medullary rays. If the cortex of old stems be torn off from the wood, the hard ends of the medullary rays stand out like little teeth of a comb from the cortex.

In other cases, cells scattered in all parts of the cortex may become sclerotic.

In some cases, they may be isolated in soft tissue, as in the bast of the pomegranate, where the stone cells in the bast of the root attain a very large size.

In other cases they form groups, annular segments, &c., inserted in the soft tissue to such an extent that they may form the principal mass of the old cortex, which in this case may be termed *stone bark*, as in oaks, firs, the *sál*, &c.

This phenomenon of *sclerosis*, in some cases, commences at the same time as the secondary growth in thickness, but in many trees, such as the silver fir and horse-chestnut, for the first few years of the trees' life, the external bark is free from sclerotic elements.

Sieve tubes, milk tubes, sclerenchyma and sacs containing crystals, &c., are incapable of further growth. Hence, as the parenchyma surrounding them expands, they become displaced

from their original position, and sieve tubes and other element with soft walls collapse from the pressure of the growing tissues around them.

This obliteration of the soft elements begins at the older zone of the cortex and gradually passes inwards.

In the cortex of *Amygdaleæ*, including the apricot, cherry, &c.,

Cherry gum.

&c., groups of tissue of varying extent become disorganised and converted into cavities filled with gum and bassorin, from which the contents of cherry-gum exude from the bursting surface of the cortex.

In the older cortex of many *Coniferaæ*, besides the ordinary resin

Resin cavities.

ducts, reservoirs filled with resin appear, resulting from the disorganization of definite groups of tissue, these may be termed *resin cavities*. They are found in the older bark of cypresses and junipers.

In addition to the changes already described in the cortex,

Periderm, or cork.

deeper ones ensue from the formation of the phellogen and its products ; all these may be included under the term *periderm*.

Thus periderm is the general name for tissues formed of cork which result from the *phellogen*.

As we have already seen, when a layer of cork is formed in the interior of a mass of tissue, the tissue outside it dries up, and is eventually thrown off the stem as bark, or *rhytidome*.

The periderm is formed in a number of layers of cork cells in radial rows, and as long as they are alive, they expand in size and also divide radially, giving rise to two radial rows instead of one at each radial division, and in this way the cork keeps pace with the increased girth of the tree.

The process of division is similar to that of the cambium, except that new tissue is formed on only one side of the phellogen.

We may distinguish living from dead cork cells, the latter forming dead cork, termed *phelloderm*.

The duration and productiveness of cork phellogen, when once formed, are very various. It may remain active for several decades, and produce masses of tissues, as in the cork oak ; or it may come to a standstill after a few sub-divisions and become itself converted into permanent tissue.

The general shape of cork cells is that of polygonal plates, the transverse and longitudinal section being more or less quadrangular, and the radial diameter shorter than the tangential.

The principal products of phellogen are—

- (i). Superficial periderm.
- (ii). Internal periderm.
- (iii). Lenticels.

In most stems of woody plants, in tubers, also in a few roots,

Superficial peri- the epidermis is replaced by periderm, arising close beneath it, and this formation

of periderm is generally coincident with the complete extension of the internode. However, in plants with a long lived epidermis, it may be deferred for many years. In a larger number of cases, the epidermis itself forms the phellogen, as in oleander, all *Pomaceæ*, willows, and some species of *Berberis*.

In *Acer striatum*, in which periderm is not formed for many years, the epidermis eventually becomes a phellogen.

In all these cases, only the cuticle is cut off by the phellogen, and it bursts and is left to peel away gradually.

In the majority of cases, however, belonging to this category, the layer of cells immediately below the epidermis becomes the phellogen, and the whole epidermis is burst and thrown off, as in *Platanus*, species of *Prunus*, &c.

In the simplest but rarer cases, only cork is produced. But in most woody plants phelloderm appears immediately after the cork. Many *Coniferae* appear to form no phelloderm.

In certain plants which are termed *suberous*, and in which

Suberous crusts. *Erythrina suberosa* is a good Indian example, and *Quercus Suber* is the best representative, numerous layers of soft, wide, cork cells alternating with thin flat-celled zones are formed, and the latter mark the limit of each annual production.

In the cork oak this may attain a thickness of several centimetres, but as the radial sub-divisions eventually fail to keep up with the growth in thickness, deep furrows alternate with prismatic projection, in old cork.

These consist of flat cells only, or of thin wide-celled layers

Suberous integuments. alternating with the former, as in the birch, *Boswellia*, guava, &c., and form

those smooth coverings of the cortex which resemble sheets of paper, and in the *Betula Bhojpatra* are actually used for paper.

In a number of stems and branches of dicotyledons and conifers, we find that a layer of periderm approxi-

Internal periderm. mately concentric with the cambium zone

is formed in the interior of the cortex, so that all parts lying outside this are cut off by the corky layer from the access of sap and die. The masses of tissue thus cut off are termed the *bark*, or *rhytidome*.

In many stems of *Leguminosæ*, as in the *A. procera*, the initial layer of periderm is in the second or third layer of cortical cells from the outside. In the casuarina and firs, periderm is still separated from the phloem by a zone of parenchyma. In junipers and many other plants, the internal phellogen lies immediately outside the bast fibres which surround the phloem.

All roots which grow in thickness according to the dicotyledonous type appear to form internal periderm. This commences in the seedling roots just outside or within the endodermis and with the secondary growth of the bundles, and by the action of the two processes the whole cortex outside the pericambium or endodermis is split and thrown off, suffering immediate decay in the case of subterranean roots, while in those above ground, it forms a number of dry flaps, as in the adventitious roots of the banyan, or epiphytic orchids. Hence most roots of dicotyledons and conifers are thinner during the secondary growth than before it, owing to the loss of primary cortex.

The products of the root phellogen are phelloderm and cork, and in the more or less fleshy roots of herbaceous plants these are often extremely thin.

It is frequently found that the cells of the endodermis wholly or partially suberise from the outermost stratum of the periderm, at its commencement, and on further growth are the first to be thrown off themselves.

The first formation of periderm, whether internal or superficial,

Repeated formation of internal periderm. is in some plants the only one, and the periderm follows the growth in thickness of the parts it encloses, as in the cork oak.

In the great majority of ligneous plants however, new internal

periderm arises successively in deeper layers of the cortex, and cuts off successively deeper zones of tissue as dry bark.

The process has only been observed to a small extent in roots.

We frequently find rings of bark stripping off horizontally, as in the cherry, *Boswellia*, and the birch, and this may be termed *ring-bark*.

In species such as the vine and cypress, when the first periderm is deep in the cortex, all the later ones assume the same arrangement, and cut off in each case an annular zone of cortex, though this is not always quite complete and regular. The bark hanging in shreds may be termed *stringy bark*.

The horse-chestnut and the *Cupressus funebris* are good examples of *stringy bark*. The bark in old trees hangs down in long strap-like layers, giving the stem a general appearance of an inverted palm. The reason for this appearance is that the internal periderm is more and more deeply seated in the older and lower portions of stem.

In species with superficial primitive periderm, on the other hand, the successive internal layers pass inwards from the outermost layer of periderm, cutting off small portions of the cortex. This is termed *scale bark*.

In scale bark the single scales have extremely various forms and dimensions even in the same tree; but there is a characteristic appearance for each species by which it may be readily recognized by the form of its *bark scales*. Thus, we have small plate-like scales in the spruce, thick oblong plates of bark in the chir, and lattice-shaped ones in the deodar. The first scale is joined at or below its edge by the peridermal layer which cuts off the second scale next to it, and belonging to the same cortical layer. The same phenomena extends round the surface of the stem without any perceptible regularity, cutting off the first cortical layer in scales, and then in the same way attacking a deeper one. The scales succeeding one another at different depths differ in form and size, so that the bark of a tree may differ in appearance at different heights along the stem.

The smooth yellowish bark of *Albizia procera* is due to the continuous growth of the cortical parenchyma, whilst thin flakes of superficial bark are stripped off here and there by the formation of internal periderm.

Foresters should learn to distinguish trees by the appearance of their bark, but in order to do so, we must consider the structure of the dried up tissue as well as its arrangement. We find all degrees of hardness and toughness in barks, owing to the occurrence of fibres and stone cells between the softer tissues, which on drying become brittle and easily crumble away. The thickness of the zone thrown off at each time is also extremely variable. In most cases, the layers of cork which cut off the bark are membranes with a few, not more than 10, layers of cells in thickness. On the other hand, internal cork may be produced in large masses forming thick strata, and consisting of many layers with concentric zone of flat and wide cell elements. This is especially the case with cork oaks.

In the case of the *Quercus Suber*, the external periderm forms to a considerable thickness on the young tree, but is rough and cracked externally and of very little practical use. When, therefore, the tree is 15 years old, this outer layer of periderm, termed the *male cork*, is stripped off until a zone of living phellogen is exposed, and then whilst the external layers of this dry up and die, a new phellogen appears below the former one around the entire stem, producing a new layer of cork, termed *female cork*. In 10 or 12 years' time, this layer is sufficiently thick to be utilized, and being say, 3 *c.m.* thick, is now peeled off like the former male one, and will again be replaced by the tree as before. This process may be continued periodically until the tree is 150 years old. If left to itself the female cork will attain a considerable thickness, pieces of 17 *c.m.* thick having been removed from a tree. If, however, the female cork were not removed at a moderate thickness, of say 3 *c.m.*, it would become split and weather-worn like the male cork.

In Russia a similar treatment is applied to the white birch, and it is possible that the bhojpatra tree, the bark of which is used as paper and for making umbrellas, might be similarly treated with advantage.

The following general rules as regards the appearance of periderm in different plants will be found useful:—

- (i). Few dicotyledons and no gymnosperms keep their epidermis for a long period, during which they form no

periderm. *Acer striatum* is a most remarkable known case, retaining its epidermis for 40 or 50 years, and after its stem exceeds one foot in diameter.

- (ii). Many trees throughout their lives, or for many years only, form superficial periderm, either as a suberous crust of smooth cortex, as *Spondias mangifera*, or as a cracked covering of cork, as in cork oak, *Erythrina suberosa*, *Excæcaria insignis*, and in several climbers.
- (iii). The greater number of woody plants form internal periderm and throw off superficial periderm and all other external cortex, as rhytidome, after various terms of years, from one to twenty.

A few woody plants form their first periderm deep down in the cortex, as in juniper, clematis, casuarina, &c., and other stringy barked species, and thus cast off all the external layers at once. This always happens in the first year, or early in the second year of the plant's life.

In case (iii), after the cortex has been thrown off, we may distinguish between three different modes in which the periderm is formed—

- (a). The shoot remains covered with the first periderm throughout life, or for many years, new internal periderm only appearing at a late period. This is the case with the pomegranate, when the one year old plant after losing its external cortex and becoming coated with periderm, may grow from 10 to 20 years in thickness before a new periderm is formed.
- (b). The first internal formation of periderm is followed by a zone at short intervals, as in the case of cypresses.
- (c). Internal periderm is produced every year and thrown off again by the production of periderm. The vine, clematis, and the honey-suckle are good examples of this class.

Sometimes peculiarities in the formation of bark occur in certain individuals of different species, but are not characteristic of the species. Thus a variety of the elm, *Ulmus effusa*, known as the cork elm, produces cork similar to that of *Quercus Suber*, whilst most plants of the same species are without it.

We also find the same tree having one kind of bark on its

upper portion and another kind lower down the stem, as in *Pinus excelsa*.

In most woody plants which form periderm, the uniform integuments are interrupted at definite

Lenticels. points by structures termed lenticels, or cortical pores. Only a very few woody plants with repeated formation of bark are without lenticels, such are the vine, certain species of honey-suckle, clematis, &c. They are very marked in the bhojpatra.

When any species forms lenticels, they are found on the stem, branches and roots.

The lenticel is a bi-convex swelling of the periderm, often projecting above the surface as well as internally. It is distinguished from the rest of the periderm by having air spaces between the edges of its suberous cells, through which the cortical parenchyma communicates with the atmosphere, whilst active vegetation is going on; during the period of rest, this connection may be interrupted by a thin layer of periderm.

The meristem in the lenticels is continuous with the other phellogen, but the cells produced under the lenticels are generally narrower tangentially than the others, and are produced more rapidly and more abundantly, layers as many as 40 cells thick being produced in certain plants.

Lenticels have a colourless protoplasmic layer lining their cell walls, with a small quantity of starch and cell sap in their cavities, and they have a great tendency to swell up during the wet weather.

When the lenticels are formed below stomata, the superficial cells are not in radial rows but arranged irregularly. They are also rounded at their corners so as to allow for air passages, and in many trees owing to this rounding, the cells have only a slight connection, and form when dry a loose powdery mass, as in the cherry, the apple and the birch.

Firmer layers appear in the midst of this loose tissue, and as they shut off the air spaces from the interior, they are called closing layers, but the closing is only temporary, as the successive layers of cork are burst through by the subsequent formation by the lower cells, which are termed *complementary cells*.



The light colour of the lenticels as compared with the surrounding bark is due to air cavities.

In many trees, as in the cherry, birch, silver fir, and *Tamarix*, each lenticel increases in breadth in proportion to growth of the shoot which produces it. In old stems the lenticels appear as large transverse sections of rings.

In other cases, as in the *Ailanthus*, the lenticels show no increase in breadth, whilst in a third series, as in the apple and paper mulberry, we find lenticels becoming subdivided into smaller ones.

The absolute size of the lenticels therefore varies with the age of the tree in many cases, and may vary from 1 m.m. to an inch in length. In a few cases, as in the plane tree, lenticels are so small as to be barely visible.

As regards the origin of the lenticels, whenever periderm appears on, or immediately below the epidermis in a slightly deeper layer, as in many *Leguminosae*, the lenticels arise below the stomata; one under each stoma when the latter are not very numerous, as in species of cherry, willow, &c. Or, when stomata are grouped together, as in the walnut and the poplar, one lenticel appears under each group. In horizontal branches we generally find fewer lenticels on the upper side than on the lower side, even when the stomata are equally numerous on either side. In superficial periderm, therefore, all original lenticels are formed below stomata.

Lenticels are also formed independently of stomata in deeper laid periderm by complementary tissue appearing in the midst of ordinary periderm and bursting through it. These new formation of lenticels increase their number.

Lenticels appearing on successive periderms replace those which are lost when the bark is separated.

In a number of plants the secondary growth in thickness of the stem and root differs from the normal growth already described, and may therefore be termed *anomalous*.

Anomalous thickening in Dicotyledons and Gymnosperms.

This may be due to various causes, and we will first describe those in which, though the cambium is normal, the tissues are anomalously distributed.

(i). **Anomalous distribution of tissues with normal cambium.**

In a species of *Heritiera* the stem does not attain the ordinary conical, or cylindrical form, but grows like a plank, being sometimes 18 inches broad and one inch thick. Several climbers, such as *Cissus*, *Piper*, &c., with strap-like stems, and the *Cassia quinquangulata* with five marked prominences on its transverse section, belong to this group. Allied irregularities are found in many roots.

The cambium may produce large masses of xylem at certain points, whilst the intermediate portions produce phloem in much greater quantity than xylem. Many Bignoniaceous climbers have transverse sections, which show this irregular growth, and in them there are generally four or more plates of phloem intruding into the xylem.

In species of *Strychnos* we find sieve tubes in bundles in the midst of the xylem and more in the phloem.

In the rhizome of *Rheum officinale*, the common rhubarb, we find phloem formed inside the cambium zone, and xylem outside it.

Examples of more than one cambium being formed occur in *Tecoma*, *Paullinia*, *Serjania*, &c., the section showing more than one ring of wood surrounded by a common bark.

It is rather a widespread phenomenon for several concentric cambiums to be formed.

In these cases, the secondary thickening begins, and often proceeds for some time in a normal way. Then a new meristem appears in the parenchyma outside the cambium, from which a new formation of bundles and medullary rays proceeds, whilst the secondary thickening of the first ring ceases. In the same way, a third zone may arise outside the second one and so on.

The successive zones consisting of wood, phloem and limited cambium resemble annual rings, though it does not at all follow that each one is formed in one year. As the phloem portion of these rings is relatively small compared to the wood, we find



broad zones of wood and narrow zones of phloem alternately. The *Cocculus laurifolius* grows in this manner; also the gauj, *Millettia auriculata*, a large climber found in sál forests. This structure is also found in the wood of *Dalbergia paniculata*, planks cut from which fall to pieces owing to the decomposition of the soft bands of phloem; in the roots of *Convolvulus*, and of the *Myrabilis Jalapa* introduced into India from Peru, and now seen wild in parts of India.

In a number of stems of *Amarantaceæ* and *Nyctagineæ*, including the *Bougainvillea*, we find a primary ring of bundles consisting of leaf-trace bundle and also intercalary bundles. Around the outer margin of their phloem a ring of cambium appears, which is extra fascicular, and remains permanently active, forming on its inner side collateral vascular bundles and intermediate tissue, on its outside a thin layer of phloem.

All the anomalies hitherto described have a concentric growth of some kind or another; but in the last case we shall refer to, we find that the old parenchyma which we already know, even in normal stems, to have a power of growth and formation of new tissue whenever the plant is injured, has in certain plants the power of continually growing even when no injury has occurred and produces secondary meristem, from which strands of wood and bast and cambium may be derived.

In a number of large woody climbers, termed *Lianes*, of which the maljhan (*Bauhinia Vahlii*), an extremely common climber in the sál and other forests of Northern India is a good example, we find that the xylem which in very young stems is continuous, containing a cross-shaped pith and surrounded by a continuous phloem, in the further growth of the stem is produced in a number of isolated bundles outside the original phloem and each one surrounded by its own phloem, so that a transverse section of a stem shows a number of bundles in which the xylem with its large pores forms the larger portion interspersed in all directions by a thinner phloem. Even in the midst of the xylem of these bundles new strands of phloem appear, subdividing them in the most irregular manner, whilst quite new bundles arise outside the older ones in the external cortex.

Owing to the power which the maljhan possesses of sending out new bundles in any direction, where least pressure occurs, its stems are enabled to force their way amongst the branches of the crown of a large tree.

We cannot distinguish the phloem from the cortical parenchyma in the darker tissues of the maljhan.

The length of *Bauhinia* internodes is greater than in ordinary dicotyledons. This is also the case with other plants of a similar habit.

Regarding Gymnosperms we need only mention that Cycads have a peculiar anomalous formation of xylem and phloem, whilst a number of successively concentric cambiums appear in *Gnetaceæ*.

Monocotyledonous axes show no secondary changes, as a rule, except in forming a superficial periderm, which often appears, especially in roots and rhizomes, but is by no means general.

A secondary thickening springing from a cambium zone and forming wood and phloem is completely absent in the large majority of monocotyledons.

After the primary bundles have appeared, the arrangement of the tissues inside the epidermis, or the periderm undergoes no further change. It is still an open question whether the internodes of palms increase in girth after their first formation, and if this be true, it is due to an expansion of the already existing elements and not to a secondary formation of the cambium.

In a few cases, however, as the stem of *Dracæna* and of certain aloes, and of a climbing *Asparagus* and the tubers of *Dioscoreaceæ*, or yams, and the roots of *Dracæna*, a cambium and secondary wood and phloem do appear.

The primary arrangement of the bundles in the above stems resembles that of the palms. After all the primary vascular bundles have appeared, the cambium is also formed in old regions of the stem, in most *Dracænas*, in aloes, near the apex.

The initial layer of the cambium is merely a layer of parenchymatous cells running round the outermost bundles.

Radial growth of this layer and tangential sub-divisions produce secondary vascular bundles alternating with interfascicular parenchymatous tissue.



The form of the cambium cells is that of erect rectangular prisms from two to four times as high as they are broad.

The shorter sides of their bases are radial and all the cells are arranged in radial rows.

The interfascicular cells, after one or more tangential divisions, become changed into wide-celled parenchyma, and the remaining cells in this cambium zone after repeated division, both longitudinal and in the radial and tangential directions, form new closed bundles, the elements of which are smaller in transverse section than the parenchyma surrounding them, and exactly resembling the original leaf trace bundles of the stem. In this way, by repeated formation of new bundles in zones between the epidermis, or periderm and the original bundle cylinder, the stem continually increases in girth, until dimensions equal to those of the gigantic Dragon tree of Teneriffe, with a girth of 50 feet, may be attained.

In the tubers of different species of yam, a cambium is formed which produces secondary vascular bundles and interfascicular parenchymatous tissue, the latter thin-walled and full of starch form the main mass of the tuber, whilst the former consists of a number of thin secondary bundles forming a net in the parenchyma.

The surface becomes early covered with a periderm which persists through life, and in *Testudinaria* attain a large size.

Secondary thickening also occurs in a climbing perennial species of *Asparagus*.

Secondary thickening of monocotyledonous roots occurs in *Dracænas*.

CHAPTER V.

ROOTS, SHOOTS, AND LEAVES.

If we consider a plant as composed of a descending and ascending axis, the former is destitute of leaves, though it is sometimes capable of producing buds from which the foliage shoots may arise.

Roots.

Root suckers.

We see this in the sissu and the sandal, when after a tree has been felled below the surface of the ground, new shoots, termed *root suckers*, or simply *suckers*, spring up from adventitious buds in the roots. *Millingtonia hortensis*, *Acacia dealbata* and other Australian acacias named wattles, the numerous suckers of which spring up at considerable distances from the parent stem, are very prejudicial to the neatness of gardens. These are, however, exceptional cases, and the stem of a plant may be distinguished as a rule from its roots by its property of bearing leaves. When, therefore, we find certain underground portions of a plant bearing reduced leaves or scales at intervals, we may assume that these are really underground stems or *rhizomes*.

A root is, therefore, an axis, whose growing point is covered by the root cap; which does not bear leaves, and in its young state is covered by a special epidermis, termed an epiblem, and destitute of stomata and of a cuticle. From the epiblem root hairs project, and absorb moisture and other nutriment from the soil.

It may be easily shown that roots are geotropical, or have a downward tendency due to gravitation, while stems have an upward tendency. If we take a small seedling and place it on the soft soil and protect it from the sun, the stem turns upwards and the root downwards. The upward tendency of the stem is readily perceived, after a crop of wheat, or mustard, has been heavily beaten down by rain or hail, and if not too mature becomes erect again after a few days of fine weather.



If such a beaten down plant be observed, we find that it is enabled to re-assume an erect position by a more rapid growth on the side nearest the ground than on the opposite side at the lower node just above the roots.

When seeds are sown on the surface of the ground no precaution can generally be taken to place that part of the seed from which the stem will arise, uppermost, but in whatever position the seed may be placed, we soon find the root proceeding downwards, and the stem upwards. The reason for this is that the upper portion of a stem which is most exposed to the light produces shorter cells than that portion which is remote from the light, the former cells having their walls rapidly lignified, and therefore, incapable of further expansion, whilst those remote from the light are still soft and expansive. In roots the reverse is the case.

Roots have also an attraction for wet surfaces, as we see from the fibrous masses of roots filling drains, and of trees growing by the water side. This is due to more rapid growth away from the wet surface.

It is evident that if the force of gravity is stronger than the upward tendency of cell formation, that the plant may assume a horizontal position along the surface of the ground. This is the case with many *prostrate* shrubs, such as the creeping juniper and the cotoneaster.

In high latitudes and elevations the woody plants which reach the extreme limit of vegetation have this character, which is doubtless assisted by the weight of the snow, resting on them for many months in the year. Thus *Betula nana* is a low wiry shrub of the extreme north of Europe, rarely exceeding 3 feet in height, and dwarf rhododendrons are amongst the last arborescent vegetation in the Himalayas. In the hills above the winter snow line, we find the stems of nearly all trees curved at their base, and this is due to the weight of the snow which slowly moves down hill as it accumulates and presses against the young stem.

In rhizomes, the pressure of the earth on the young shoot also compels the plant to grow horizontally for a time, and many ferns and other perennials form rhizomes which persist under the snow, and only send up shoots after it has melted, these shoots dying down at the approach of winter.

In most dicotyledonous plants, we find a main descending axis, termed the *tap-root*, in direct continuation of the stem, from which side roots develop

Tap roots. in rows corresponding to the xylem plates of its axial bundle, and ramify again and again to several degrees. The very youngest of them, as well as the end of the tap root, bear root-caps and root hairs, which fall off, together with the epiblem and cortical parenchyma after or during the first year of their formation. The whole mass of roots may be termed the *root system*, and its mode of expansion in the case of any individual plant depends on the soil in which it may be growing as well as on certain characteristics of the plant. In a poor dry soil, the roots are long and few in number, as in the *Rakhs* of the Punjab and Sindh, and in the Bhábar of the N.-W. Provinces and Nepál. The tap root of certain species, such as the jand (*Prosopis spicigera*) and the sál, attain lengths exceeding 60 feet, growing down towards a permanent water stratum, and thus the porous nature of the soil or the dryness of the climate always favours the prolongation of the tap root.

In temperate climates, the tap root has not generally a prolonged vitality, but numerous side roots, springing from the base of the stock, spread out horizontally to considerable distances from the stem. This is the case in India with various species of *Ficus*, tún and other trees growing in moist soils, which are said to be *shallow-rooted*.

The numerous fibrous roots which may be induced to grow within a foot or so of the surface of the ground, as in a mango tree, by copious application of manure and moisture, may be termed *surface roots*.

In Europe, it is customary in the case of trees, other than conifers, to reduce the length of the tap root of seedlings intended to be transplanted, by cutting off the lower part with a sharp instrument, and at the same time removing a portion of the stem so as to keep up the proportion between the latter and the roots. New superficial roots are now produced, and the plant is far more suitable for planting out, either in a naturally moist soil or where it can be irrigated.

Similar results may be attained by having a paved floor to the nursery, or by transplanting several times before a plant is put



into its final position in the forest, as numerous strong side roots are then produced near the *collum*, or line of junction between the root and the stem.

In the dry soils of Northern India, however, it is found that injury to the tap root is generally hurtful, if not fatal, to the plant, as the long tap root of many Indian species is required to draw up the water from below, and transplants of sissu, with tap roots 6 feet long, are carefully planted out in the Oudh forests.

Certain plants growing in swampy ground have hardly any roots at all, as the *Drosera*. In the case of many plants, such as the pipal, growing temporarily in dry places, such as the cleft of a rock, fork of a tree, or in a wall, the tap root swells up like a carrot, containing a quantity of reserve material, so that the plant is enabled to live, until its aerial roots, which grow rapidly in length during the monsoon months, have reached the ground.

In the case of a caoutchouc tree (*Ficus elastica*) germinating on a lofty forest tree, many years may elapse before the numerous aerial roots have reached the ground, and during this period the milky latex assists in retaining moisture in the plant during the dry season, which is generally confined to four or five months in climates favorable to the *Ficus elastica*. We have already described the modified root-systems of parasites.

In monocotyledons, taking the date palm as an example, germination commences by the protrusion of

Roots of monocotyledons.

the caulicle through the testa. The root then ruptures the common sheath of root and stem, and in the palmyra forces its way down to a considerable depth. But such roots do not expand in girth, and as the palm grows upwards, more and more numerous adventitious roots spring from the base of its stem.

We have already seen that the root hairs are only produced just

Root hairs used for nutrition of plants.

above the root caps, on the youngest portion of the plant's root system, and as year by year this system expands, fresh soil is constantly acted on. If, therefore, we prune away any of the roots, or they are destroyed by insects or disease, as is frequently the case, there is danger of the plant being starved, as the soil immediately at its base has been already deprived of much of its nutriment. Hence the necessity

for manuring the roots of such injured plants, also of pruning their stems and branches.

We frequently find that tuberous masses of roots capable of absorbing larger quantities of moisture than the normal rootlets, are produced above those that have disappeared, and give the plant a better chance of recovering. This is commonly seen in transplanted deodar seedlings.

The whole principle of taking *cuttings* or *layers*, depends on the production of *adventitious* roots, springing from any portion of the plant, even from the leaves, as in *Bryophyllum* and *Begonia*. The production of adventitious roots is encouraged by absence of light and a moderate supply of moisture, and cuttings should, therefore, be shaded and placed in permeable damp soil, the greatest care being taken to ensure thorough drainage, as a sour soil would be injurious. In *layers*, a branch is bent down into the soil, or into a pot full of soil.

Adventitious roots are generally produced at the nodes of a plant, so that in making cuttings we should sever the stem just below the node.

In the ivy (*Hedera Helix*) the numerous adventitious roots bind the creeper to the stems of the trees to which it is attached. The same is the case with several species of *Ficus* and orchids and peppers. In some of these cases the plants have no roots in the ground at all and are *epiphytes*. The ivy, however, uses its adventitious roots principally as a support. In certain species of mangroves (*Rhizophoreæ*) the aerial roots grow in the greatest profusion, forming arched scaffoldings, which support the stem above the level of the water ; in these trees also the seeds germinate while still attached to the branches, and the long tap roots of the seedling hang down like ropes in all directions, until the young plant falls down and becomes rooted independently. In this way, in muddy back waters, new plants constantly encroach on the water.

The medullary rays in roots are frequently of considerable size, and they as well as the bundle parenchyma serve as reservoirs for reserve material. We are all familiar with fleshy tuberous roots, as those of the carrot, turnip, tapioca, &c.

The capability some trees have for *coppicing*, is due to the quantity of reserve material which roots contain. The base of a felled tree



the latter are to the soil, the more strongly rooted shoots will they produce.

From what we have seen, it is evident that, we should cut our stem intended for coppice growth so as to leave the edge of the stool close to the ground, and then any shoots which may arise will be in the best position for independent growth.

The base of the stem of a plant, at its junction with the root, is termed the *collum*, and on any injury to the parent stem, adventitious buds in the collum frequently gives rise to *collum shoots*, which are commonly produced by the *sál*, and if these be repeatedly destroyed by frost or fire, the collum expands into a large woody flat disk, giving out numerous shoots yearly, which do not become strong stems unless protected from the annual cause of destruction.

Owing to the gradual heaping up of the soil above the collum of a plant, dormant buds are frequently found underground, as in the *sál*, and give rise to vigorous shoots after the tree has been felled.

We must distinguish these shoots from root-suckers.

If we make a transverse section of a stool through a young coppice shoot, we find that the base of the latter forms a spoon-shaped wedge of living tissue, in the midst of the dead stool, and this wedge rapidly isolates itself from the external dead wood and bark by the formation of periderm; it also sends out adventitious roots into the soil, so that in a short time it becomes perfectly independent of the old stool.

Stool shoots may be distinguished from seedlings by the spoon-shaped section of their bases, although cylindrical from a short distance above the soil, and by their curving inwards near the ground, though this latter characteristic is also caused by the snow, in the case of hill trees. They also generally form a circle round the old stool, though in many cases, as frequently in the *sál*, only one or two such shoots arise.

When a very young stem is injured and felled close to the ground, it is frequently very difficult to distinguish the vigorous young shoot which may replace it from a natural seedling.

Such a shoot from a very small stool may grow over the tap root of the former and preserve it from decay, but it is a rule that

any injury to the stem or crown of a tree is followed by the decay of a certain part of the root system.

Every part of a plant which increases in length by its terminal bud and produces leaves or leaf-like organs, is termed a *shoot*, and is distinguished

The ascending axis of plants. from a root by the absence of a root cap at its terminal point, and of root hairs, and by the presence of stomata on its epidermis.

The *hypocotyle* is intermediate between the stem and the root, and is so termed owing to its being below the cotyledons.

Shoots may be divided into three regions—

- (i). The leaf-scale region.
- (ii). The leaf region.
- (iii). The bract region.

The *leaf-scale region* is generally subterranean, and resembles a root, or an enlarged fleshy bud. Leaves on it are never green, but are fleshy or membranous and of simple forms, resembling the leaves we find outside a bud.

The leaf-scale region is principally developed in the case of herbaceous perennials, forming rhizomes or underground stems, which may live on indefinitely, whilst the foliage, stem and inflorescence die down every year.

Such are the *bulbs* of lilies and onions, *corms* of *Gladiolus* and *Calladium*, tubers of yams, Jerusalem artichoke and potatoes. In some plants tubers are formed in the axils of the leaves, and are then termed *stem tubers*, as in many species of *Dioscoræa*, the bulb-bearing Egyptian onion, and in some lilies such stem tubers become eventually detached from the parent stem, and falling to the ground, take root and produce new individuals.

Corms differ from *bulbs* in the absence of the sheathing, fleshy scales of the latter, and from rhizomes, in their more or less globular appearance, and the regularity with which they split up into smaller corms. They have only one or two sheaths, and are practically solid bulbs.

Stem tubers are sometimes called *bulblets*, and in certain species of onions we find the edible bulbs growing in the air instead of in the ground, being really the buds of the undeveloped inflorescence.

From all the above cases it is evident that bulbs are merely



is termed a *stool*, and the young shoots which may spring from it **Coppice shoots.** are termed *stool* or *coppice shoots*. They may spring either from *adventitious* or *dormant* buds.

The normal place for buds to appear is in the axil of a leaf, and any bud springing from any other part of a plant is *adventitious*. It does not follow by any means that all the buds which may be formed should develop into branches; some die off from attacks of insects and other causes, whilst many, though preserving their vitality, merely keep their terminal points above the bark of the plant. These are termed *dormant buds*, and always originate in the axil of a leaf of a yearling stem or branch, and, therefore, in the older tree the dormant bud is always connected with the pith.

In plants, such as oaks, where a number of bracts are produced at the terminal shoots, at the close of each year's growth, each of these bracts should have its axillary bud, and hence such plants generally possess a number of dormant buds and coppice freely.

Plants with accessory buds, as *Cordia myxa*, are also likely to have many dormant buds, and *shade-avoiding* plants, such as the sissu, which only develop comparatively few branches, will have more dormant buds than *shade-enduring* plants, such as the jaman or mango, which are generally very branchy.

Dormant buds are very rare in conifers, as all the axillary buds produce *fascicular leaves* in many species, which are really brachiblasts, and thus become incapable of producing shoots if the tree is felled.

Conifers also do not produce adventitious shoots from their stems, but may be made to produce adventitious roots, and hence cuttings of *Cryptomeria japonica* and some other conifers readily strike when placed in the ground.

We find dormant buds in the young chir, and in the yew. With the increasing age of a tree, dormant buds lose their vitality.

Some buds only pass a certain distance through the wood in which they remain imbedded, and are said to be *suppressed*, whilst others develop short branches, termed *brachiblasts*, which only protrude a few inches from the stem, and these may annually put out one or two leaves. The fruit-bearing twigs of pears and apples are *brachiblasts*.

Dormant buds may ramify, and in certain cases their ramifications are very numerous, as in old *pollarded* trees, from which the crown is periodically lopped off. The knobbed appearance of many trees we see in hedgerows and the so-called *bird's-eye* marks in maples, &c., are due to numerous dormant buds close together.

The *burrs* of the walnut and other ornamental woods are highly prized when sawn up for cabinet work.

When a tree has been felled and the stool left *in situ*, owing to the quantity of reserve material it contains, many buds which have long remained dormant at the base of the stem are now recalled into activity. From these buds new shoots arise, forming a circle of more or less numerous stool shoots, round the old stool.

Besides the shoots from dormant buds, others arise from the cambium zone, which is exposed in a ring
Adventitious shoots. at the top of the stool of a felled tree.

The living tissue of the cambium relieved from the downward pressure of the trunk forms a small circular ridge projecting above the surface of the stool, and periderm appears on the surface of this ridge, the new growth gradually expanding in a series of cushions which intersect, and tend to cover up the section. The tissue formed beneath this periderm, and termed a *callus*, produces ordinary woody tissue.

At certain points of the callus, the cambium assumes the properties of a primary meristem producing new terminal buds, and these having no communication with the pith of the old stem are adventitious buds, and the shoots arising from them are adventitious shoots.

The cambium below an adventitious shoot, supplied continually with new nourishment as the little shoot becomes covered with an expanding foliage, forms a wedge between the decaying bark and the wood of the stool, the duration of which depends on its hardness and other causes, but which must ultimately decay in every case. From this wedge, adventitious roots burst through the bark into the soil, so that after a few years, the young plant is capable of independent existence.

But these adventitious shoots, situated on the top of a stool, are much more exposed to be dried up or to be broken off by cattle or otherwise injured than shoots from dormant buds, and the nearer

modified buds, the scales of which generally become fleshy and richly stored with reserve material. Bulbs remain dormant underground during the cold or dry season, and with the rising temperature or the advent of moisture in the monsoons, send up long vigorous flowering stems, as in *Lilium grandiflorum*, which in a few days or weeks over-top the mass of herbaceous vegetation in which they may be grown. These stems die down again with the approach of winter or drought.

Other forms of prostrate, or *underground* stems, are termed rhizomes, as in bamboos. They are generally elongated with a terminal bud at one end and axillary buds in the axils of some of their numerous scales.

The terminal bud of a rhizome, as in turmeric, ginger, cardamoms, &c., frequently merely grows in length, and does not produce herbaceous shoots, which, however, spring up annually from one or more of the axillary buds in the scales behind it. The scars left on the rhizome by the shoots which have already died down have given the name of Solomon's seal to certain plants of this nature.

Most rhizomes are chiefly parenchymatous and full of reserve material, but become woody in bamboos, and lose their meristematic property, so that only the younger rhizomes in a clump can produce fresh culms. The seedling during the first year sends out a very weak culm from its rhizome. In the second year, the rhizome branches and produces several culms somewhat stronger than before, and so on in successive years, until after an interval of say ten years full sized culms are produced. In most bamboos, the terminal point of the rhizome does not travel far, and two kinds of buds are produced on it. One kind gives rise to branches of the rhizome, whilst from the other kind the culms arise. In bamboos, it is frequently the terminal shoot of the rhizomes which produces the culm. Owing to this branching of the bamboo rhizomes, a confused mass of rhizomes and roots piled one above another is frequently produced surmounted by a clump of culms.

There is a bamboo growing in the Garo Hills and in Burma, which instead of forming clumps, sends out rhizomes through the soil in all directions, and from these, culms spring up here and there from the axils of their scales. In this way immense tracts

of country are covered with a dense growth of these bamboos, 40 feet and upwards in height, and not growing in clumps like ordinary bamboos.

The shoots from bamboo rhizomes differ from the herbaceous ones we have referred to above in their persistency, and in practice it is found that bamboos continue to harden and improve technically, by lignification of their tissues and by containing less reserve material, during the first four or five years of their life, after which they deteriorate and decay.

The age of the culms can generally be determined from their external appearance.

It is evident that bamboos which do not produce long branching rhizomes only form isolated clumps. Bamboos invariably produce seed after a certain number of years, about 40 years in the case of *Bambusa arundinacea*, and at the seeding, it generally happens that all clumps of the same species of bamboo blossom gregariously; this general seeding being followed by the death of all the clumps. The young seedling annually produces continually larger culms until the clump has attained its full size after from 5 to 10 years, when it produces full size culms, which in the larger bamboo (*Wabo*, *Bambusa Brandisii*) of Burma attain a diameter of 8 or 9 inches with a height up to 120 feet. *Dendrocalamus strictus* is the bamboo of the Siwaliks and Central Provinces, the lower part of the culm of which is frequently solid, and is called the *male* bamboo.

Young culms of bamboos bear large scaly bracts at their nodes, which fall off soon after the culms have attained their full height, and give rise to numerous branchlets bearing the true leaves.

The region of a stem which bears green foliaceous organs, growing above the soil, either in the air or in the water, and exposed to the influence of light, is termed the true *leaf region* of plants.

The leafy shoots of the strawberry are termed *runners*, and proceed to a certain distance from the parent plant before they take root and produce a new plant.

The *house leak* produces shorter shoots which persist after the original plant has died down, and thus from a centre numerous plants gradually spread out in all directions.



Every kind of woody plant has a special appearance due to its mode of branching, by which it may be readily distinguished from others. Thus

Habits of trees.

we have the *flat crowned Albizzia stipulata*, the *scantily branched Albizzia procera*; the semal with its apparently *verticillate* ramification, the *pendulous stem* of the young deodar which becomes flattened and *tabular* when old; the *conical* shape of young sál, spruce and silver fir, the crown of the latter becoming cylindrical in dense forest.

We find shrubs, especially near the top of mountains and other exposed places, the leading shoot of which grows along the surface of the ground, whilst only some lateral shoots become erect and attain a height of only 1 or 2 feet. Such *shrubs* are said to be *prostrate* or climbing, as the *Juniperus recurva*, and the *Cotoneaster*. Such plants easily resist the weight of masses of snow.

Trees present a different habit when isolated than when growing in a dense forest. If a deodar tree is growing in the open, its stem will be covered with branches spreading out horizontally down to the surface of the ground, giving the whole tree a *pyramidal* appearance, whilst the same tree grown in dense forest will have a lofty bole sometimes exceeding 120 feet in height without a branch, and surmounted by a scanty crown. We all know the appearance of a mango tree growing alone in the middle of a field, the crown of which terminates abruptly all round the tree at the same height of a few feet from the surface of the ground, the downward growth of the branches being probably arrested by the heat reflected from the ground. The same tree if grown in a grove will have a bole of 30 to 40 feet in height below the crown.

As example of trees of peculiar habits, we have the *weeping* willow and the *pyramidal* cypress.

Woody plants are distinguished as follows:—

Length of bole.

Tree,	{	Large tree, over 80 feet, e.g., sál, deodar and teak.
		Moderate sized tree, over 50 feet, sissu and babul.
		Small tree, over 25 feet, box, yew, zizyphus and sandan
		(<i>Ougeinia dalbergioides</i>).
Shrub,	{	Arborescent (with a bole),
		Branching from the base,
		} under 25 feet.

When a shoot has a bole and resembles a tree in miniature, it is said to be *arborescent*, as the orange, *Limonia acidissima* and *Lagerstrœmia indica*.

Other kinds of shrubs branch out from near the base, as the *Vitex Negundo*, *Adhatoda Vasica*.

Bush.—A low branching woody plant, as a rose bush, berberis, certain species of *Zizyphus*, and *Capparis aphylla*, which sometimes attains the dimensions of a shrub.

By ill-treatment, such as exposure to grazing and jungle fires, frost, and owing to unsuitable soil or to a rigorous climate, as tops of mountains, we frequently find that forest trees assume a bush-like appearance. In certain low damp situations in the Dûn, we find the sâl tree kept down by frost in this bush-like state.

Climbers are plants, which, in order to attain full dimensions, mount by becoming attached to rocks or to the stem of some shrub or tree.

Climbers.

Climbers may be herbaceous as the pea, or woody as the maljhan (*Bauhinia Vahlîi*).

Climbers may be distinguished as *twiners* when their stems wind round those of their supporters, and the winding may be either from left to right or right to left, each species of climber always turning in the same way.

If the coil is from the left to the right hand of the observer, who is supposed to be standing in the position of the stem round which the plant is twining, the twiner is said to be *dextrorse*, and in the opposite direction *sinistrorse*.

Certain plants, generally of small size, creeping along the surface of the ground or of some other plant, by means of their adventitious roots, are termed *creepers*. Certain species of *Ficus* for example come under this head, and the ivy is really a gigantic creeper.

We may speak of climbers, twiners, and creepers which are injurious to forest trees, under the general term of *climber*.

Woody climbers and twiners may attain a girth of several feet with a sufficient length to enable them to reach the summit of the highest forest trees. The maljhan is a good example of the former, and is very common in the forests of Northern India.

The gauj (*Millettia auriculata*) is also very common in sál forests, winding round the trees which it constricts in its embrace, giving their stems the shape of a screw.

Injuries done by climbers to their hosts, are—

- (i). Deprivation of light. The spreading crown of the climbers overshadowing that of the tree.
- (ii). Torsion, and perhaps fracture of the stem and crown of the host by the great weight of the climber, and this is especially to be feared in the case of saplings and poles.
- (iii). In the case of twiners we have a third source of injury in the compression of the cambial zone, and of that portion of the stem through which nourishment passes, by the coils of the twiners.

A twiner in its young state generally assumes a shrub-like appearance, but sends out long shoots, which revolve naturally by a process termed *nutation*, until they strike some neighbouring stem, and by its support their comparatively feeble stems may be enabled to mount to the summit of the highest tree.

Climbers and twiners, therefore, in order to get their crowns above the surrounding vegetation, and thus gain for themselves a place in the struggle for existence, which their own unaided efforts would never attain, profit by the assistance of massive forest trees which by steady increase in girth during a number of years have gained a place which these climbers with their help may attain in a few years.

Climbers support themselves in various ways, the ivy by tufts of adventitious roots attaching themselves to the host.

Species of *clematis* by their petioles, which wind round the little branches. Other climbers by tendrils which are modified leaves, as in the case of the maljhan and various kinds of pea, or modified branches, as in the vine and other species of *Ampelidæ*. In some vines, the tendrils penetrate the bark and grow in it like the adventitious roots of the ivy. The different species of *calamus* ascend by hooks on their leaves.

Twining stems wind round their host by growing more rapidly at their outer surface than at their inner surface in contact with the host which presses on their meristem.

Stems may be cylindrical, prismatic, or fluted, as in the Cactus and Euphorbia. They may be foliaceous, as in the Cocaloba.

Shape of stems.

The leaf-like organs of ferns, mosses, lycopods, and other cryptogams are really branches, as they bear the organs of reproduction, and are termed *fronds*. They, however, contain chlorophyll, and act as leaves in assimilating nourishment for the plant.

In the case of duck weed (*Lemna*), the whole plant is a flat green plate, sending out roots from below and flowers above.

Upward growth is frequently arrested, as in the teak and sál, by the terminal bud giving rise to inflorescence; unless then, a lateral bud can replace the leading shoot, the growth in height of the plant ceases. In trees with lateral inflorescence, as the deodar and oak, immense heights may be attained.

One of the mammoth trees of California (*Sequoia gigantea*) has attained the height of 450 feet and diameter of 35 feet. In another, 25 feet in diameter and perfectly sound, 3,000 rings were counted, so that even if more than one ring were formed in one year, and this is unusual with conifers, the tree must be of immense age.

A chestnut tree at Mount Etna is said to be 2,900 years old, and an ivy at Fontainebleau 1,132 years old.

In spite of these great ages, few trees except conifers exceed 200 years with a sound stem. Sir D. Brandis considers that 150 years is required to produce deodar 6 feet in girth, whilst in Oudh probably 80 years will suffice to produce sál of the same dimensions; he estimates that a teak tree in Burma 160 years old may be 6 feet in girth. A teak tree in Java 100 years in age has a diameter of 4 feet.

Certain Australian eucalypti, which like conifers have axillary inflorescence, exceed the sequoias in height, one having been measured 400 feet in height with a girth of 8 feet at 80 feet from the ground.

Deodar has been measured up to 45 feet in girth, and 250 feet high.*

Antiaris innoxia of the Western Ghauts is the loftiest tree of the

* *Vide* Brandis' "Forest Flora." Deodar at Nachar, in the Sutlej valley, 250 feet high, 20 feet girth and over 350 years in age.



evergreen forests there, and another species in Tenasserim allied to *Antiaris toxicaria* (the famous Upas tree of Java and the Indian Archipelago) has been measured with a height of 250 feet and a girth of 38 feet.

Sál trees have been measured to a height of 150 feet with a girth of 25 feet, but such dimensions are exceptional, the finest sál trees rarely exceeding 15 feet in girth and 50 feet to the first branch.

Teak trees have been measured in the Anamalais with a girth of 22 feet and 90 feet to the first branch, and in Burma, instances of 25 feet girth have been recorded, with a total height of 150 feet.

In the Ahiri forest, Central Provinces, 18 teak trees were measured by Col. Pearson on one acre, containing 1,100 cubic feet of timber, most of them about 200 years old.

Leaves are special lateral out-growths from the stem, definitely and systematically arranged upon it, as has been already explained. In ordinary vegetation the mass of leaves, or foliage, constitutes the assimilating apparatus of plants, viz., for the conversion of inorganic into organic matter, which takes place in all the green parts of plants exposed to sun-light.

In certain plants, which are termed *aphyllous*, the green stem and branches supply this function, as in the *Coccoloba*, which, however, has small temporary leaves, or in the duck weed (*Lemna*), the stems of which resemble leaves in their shape. We may also include the camel-thorn (*Capparis aphylla*), which is generally leafless, though new leaves appear on the young shoots from November to March.

Certain leaves quite lose their assimilating properties and become serviceable to the plant in other ways—

- (i). In affording protection to buds, such leaves being generally termed *scale leaves*, as in the horse chestnut (*Aesculus indica*).
- (ii). For storing reserve material; as in the coats of an onion.
- (iii). As *floral bracts*, forming parts of the inflorescence.
- (iv). As *tendrils*, to assist climbing plants, as in many *Leguminosæ*.

- (v). For protection against animals, as in the prickles of *Berberis* and the leaves of thistles.

We may also consider leaves as serviceable in different periods of the plant's life—

- (a). During the foliage period.
(b). During the floral period, when modified leaves form the blossom and the rudimentary fruit.
(c). During the ripening period, when the fruit is a modification of the petiole, or leaf-blade, and the seeds are modified buds.

Perfect foliage leaves consist of petioles and laminæ. If the former be absent the leaf is said to be *sessile*. We frequently find a protuberance at the base of the petiole, termed the *pulvinus*, and the movements noticed in certain leaves, as in the sensitive plant, are due to changes in its tissues.

In certain leaves, we find a sheath at the base of the petiole more or less surrounding the axis. This is termed the *vagina*, or *sheath*, and is largely developed in palms and grasses.

Stipules are appendages of the sheath, and are sometimes found at the base of the petiole, and may be either deciduous, as in the pipal, or persistent, as in roses. They are well marked in *Albizzia stipulata* and in the genus *Ficus*.

Leaves may be either *simple*, or *compound*. The latter have a common petiole, from which leaflets project on either side; the petiole may itself be branched, and this branching may be repeated several times, the last divisions of it bearing the ultimate leaflets, or *pinnæ*.

Leaves in which the petioles are subdivided more than once are termed *bi-* and *multi-pinnate*.

In certain cases, the petioles of a leaf become expanded, whilst its lamina is either only partially developed, or completely absent. Such leaves are termed *phyllodes*, and are commonly found in Australian acacias, where they have the peculiarity of being expanded vertically instead of horizontally as are ordinary leaves.

Forests of Australian acacias are thus enabled to present the smallest surface of their leaves to the sun's rays, and so preserve sufficient moisture through the dry season.

Leaves are generally expanded horizontally so as to secure the

greatest amount of light, and when from the position of a leaf on a branch the horizontal arrangement is not normal, this position may be secured by a twisting of the petiole as in vines.

The leaves of certain lilies, grasses, &c., are, however, vertically arranged, and so are the leaves of many Australian eucalypti, which act like the phyllodes of acacias in preventing excessive transpiration.

The blade of certain leaves, as in *Nepenthes*, becomes converted into an open cup, containing a sweet liquid, which attracts insects. This secretion has a certain digestive power, and plants thus supplied with what are termed *ascidia*, or pitchers, are enabled to obtain a supply of nitrogen from the animals they capture. A similar phenomenon occurs in the case of *Utricularia*.

Leaves have different properties at different seasons of the year, and also when evergreen leaves persist for several years, the older ones have different properties to the younger ones. Those leaves are termed *caducous*, or *fugacious*, which only have a very temporary duration, whilst leaves which remain on a plant only for twelve months or a lesser period, are termed *deciduous*.

Leaves on the other hand, which remain on the plant for more than 12 months, are termed *persistent*, and plants bearing such leaves are termed *evergreen*.

As an example of *caducous* leaves, we have the stipules of the *Albizia stipulata* and the leaves of the thor (*Euphorbia Royleana*), which only persist during the monsoon.

The semal or the mulberry are examples of *deciduous* trees.

We may distinguish plants losing their leaves at the commencement of the *cold* season, which we may term *cold weather leaf shedders*, as the semal, tûn, mulberry and sissu, from those, which, like the sâl and the teak, shed their foliage in the *hot* season. These may be termed *hot weather leaf shedders*.

The first tree to lose its leaves in the North-West Himalayas is the walnut, which frequently becomes bare before the end of September. The mulberry and the willow are probably the first trees to become leafless in the Dûn.

As regards evergreens, certain trees, such as the karshu oak (*Quercus semicarpifolia*), do not lose their leaves until the new ones

appear, thus retaining them slightly over 12 months, and in certain seasons, these oaks appear to be really deciduous.

It is a law of nature that one type passes insensibly into another, without any very clear line of demarcation, and trees, such as the sál, may retain their leaves under certain circumstances for a less or greater period than 12 months, so that doubts may arise whether they are really evergreen, or deciduous.

Amongst evergreen trees conifers form a marked type, the larch being the only conifer known in the Old World, as deciduous. There is a species of larch (*Larix Griffithii*) growing in the Eastern Himalayas.

Evergreen trees other than conifers are most abundant in damp hot climates, and the moist evergreen forests of the Western Ghats and of Burma and Assam contain numerous species, of which the nageswar (*Mesua ferrea*) is a widespread example. Conifers, however, are generally characteristic of cold climates, and in India are found at considerable altitudes above sea level, the most tropical conifer, the Tenasserim pine (*Pinus Merkusii*) growing down to 2,000 feet above sea level.

Regarding the persistence of the leaves of conifers, those of the chir (*Pinus longifolia*) do not persist for more than 13 months, and in certain situations this tree is actually deciduous.

In *Pinus excelsa*, the leaves may persist for 3 or 4 years; those of the deodar from 3 to 5 years, the spruce 5 years, and silver fir 8 to 10 years.

The yew is another conifer, the leaves of which persist for several years, and it thrives in dense shade.

The formation of a zone of cork at the base of the petiole of the leaf of dycotyledons and gymnosperms has been already explained, this zone cuts off all nourishment from the blade, and some of the cells above the corky zone become loosened, and separate from one another without any rupture of the cell walls: thus, eventually the leaf falls, leaving a clear scar, in which the ends of the fibro-vascular bundles may be distinguished.

In cases of frost occurring before the cork layer has been formed and killing the foliage of the plant, the dead leaves remain attached to the plant for a long period. Such leaves can only be removed by actual rupture of the cell-wall. In *Quercus serrata*, the only

deciduous Indian oak, the dead leaves may remain on the tree in Dehra Dún till the bursting of the spring buds.

The fall of the leaf in the case of some hot weather leaf shedders, as the sál, is expedited by the swelling of the axillary bud. This is not generally the case with cold weather leaf shedders: but the common willow of the Dún (*Salix tetrasperma*) produces new foliage in November, as soon as the old foliage has fallen.

In case the whole foliage of a tree be destroyed by any cause, such as severe frost, attacks of insects, forest fires, &c., a secondary foliage is generally produced, even in the midst of the growing season.

Such a secondary foliage may be noticed in May, June, or even in July in the private sál forests in Dehra Dún which have not escaped fire, whilst the normal foliage in protected sál forest appears in March and April.

It is evident that the production of such a secondary foliage must task the vital powers of the trees very greatly, as the nutritive material intended to supply new growth is spent on this secondary foliage, and if this ill-treatment should happen annually, sál and other trees so affected cannot attain their full dimensions.

The defoliation of hot weather leaf shedders, such as the teak, is accelerated by draught, and retarded in moister regions like Dehra Dún, where the leaves sometimes remain on the trees until June, and the buds only begin to swell at the commencement of the monsoon, when the new foliage appears.

With the diminishing temperature of the cold season, the chlorophyll in the foliage of most cold weather leaf shedders, as well as many evergreen trees, becomes changed in colour as well as in composition, and this change gives rise to the many varied autumnal hues of temperate forests, and the spring tints in sub-tropical forests. These hues vary from different shades of yellow, as in the sál, to shades of brown, or scarlet, as in the piáman (*Eugenia operculata*). The cold weather copper tints of the foliage of the bákli (*Anogeissus latifolia*) colours whole hill sides. Such coloured leaves may persist for several months on the tree.

In certain evergreen trees, such as the thuja, the yew, some species of cypress, the box and the myrtle, the chlorophyll becomes reddish brown during the cold weather, giving the foliage a rusty

appearance; the green colour re-appears, however, when the temperature rises in the spring.

In certain deciduous plants, on the contrary, such as the plum and alder, the foliage falls when quite green, without any change of colour. Certain varieties of some species of plants have gold coloured foliage, as in thuja and *Bambusa aurea*, and in such cases the golden colour first changes to green and then to reddish brown. In every case, the autumn colouring of leaves is due to a change in the contents of their cells and not of the cell wall.

We have already spoken of cases in which chlorophyll is masked by a reddish colouring material termed erythrophyll. This is very common in seedlings, as those of the mango, but in certain plants, as the copper beech and in ornamental species of *Dracena*, copper or red foliage is found throughout the life of the plant.

Begonias, coleas, crotons and many other plants with richly variegated foliage adorn our gardens.

Whenever white streaks prevail, as in ribbon grass, this is due to air cavities or cells under the epidermis destitute of chlorophyll.

In evergreen plants, it is evident that only a portion of the foliage is replaced annually, so that forest fires or attacks of insects, or frost, by destroying the foliage of an evergreen plant, are more hurtful than to deciduous plants, which would naturally produce the whole of their foliage annually. It is owing to this cause, as well as to the fact that conifers are generally destitute of dormant, or even of lateral buds, except close to the terminal ones, that attacks of caterpillars have destroyed large tracts of pine forests in Germany.

We see in the case of the mulberry, and of *Machilus odoratissima* of Assam, the foliage of which is eaten off by silkworms every year, how extremely hardy deciduous trees are in this respect. It is evident, however, that though the trees are not killed by the continual removal of their foliage, yet that very little growth in their stems can take place.

Exotic plants, especially if brought from the Southern Hemisphere, such as Australia, have quite a different period of leaf-fall from that of indigenous plants, but it has been found in the Nilgiris that the Australian trees planted there have gradually adopted a date of leaf-fall suitable to the local climate.



In certain species of trees, such as the Lombardy poplar and the casuarina, the small twigs at the end of the branches are jointed and fall off at the end of the year. In

The fall of twigs.

loquats, towards the end of the monsoon, numerous small branches die yearly, and the dead foliage they bear remains for some time persistent.

We may consider cotyledons as a form of scale leaf, and in some cases, as in acorns, they remain enclosed

Primordial leaves.

in the seed, from which the plumule and radicle protrude after germination.

Thick fleshy cotyledons remaining inside the testa after germination always belong to ex-albuminous seeds (seeds without an endosperm).

In the case of albuminous seeds, as in those of pines, however, the cotyledons with the plumule, after absorbing the material of the endosperm, issue from the encasing testa and assume a more or less leaf-like appearance, containing chlorophyll, but differing from true foliage leaves in their more fleshy texture, simple shape, and absence of marked nerves. The young castor oil plant, for example, does not grow at first as the pea or bean, from the reserve material contained in its cotyledons, which in this case act as true leaves assimilating nourishment from the air. It is started in to life by the nourishment afforded to its caulicle by the endosperm which becomes gradually absorbed, whilst the cotyledons rapidly assume the form and appearance of true leaves and assimilate nourishment from the air, which feeds the plant until its foliage can find time to develop.

In the albuminous seeds of conifers, a number of cotyledons, from two to twenty, are enclosed, resembling the needles of the mature plant.

Leaves immediately succeeding cotyledons in the stem sometimes differ in shape from the normal leaves, and are termed *primordial leaves*, and on examining the upper portion of the stem of a young plant, we find more and more perfect leaves are produced higher up. In other cases, primordial leaves are more complicated than the normal leaves. Thus the lower leaves of a jack tree are *pinnatisect*, whilst the normal leaves are simple, and the case of the phyllodes of the Australian acacias has been already described.

The large scales found on the young culms of bamboos are of the nature of primordial leaves. They are without chlorophyll whilst still enclosed in the terminal bud, and are really protective organs of the latter, being frequently covered with strongly silicious hairs.

In many conifers, the normal leaves are produced in little tufts at the ends of what are really suppressed branches; these are termed *fascicular* leaves. The primordial leaves of conifers are not fascicled, and are softer and contain fewer resin ducts than the normal fascicled leaves. These primordial needles are only produced in young plants, and are succeeded by numerous overlapping scales which cover the whole stem of conifers, from the axils of which the fascicled leaves arise. Many conifers, such as cypresses, thujas, &c., have merely green scale-leaves. The ginkho (*Salisburya adiantifolia*) has broad flat leaves, like those of the maiden-hair fern (*Adiantum Capillus-Veneris*). The fact that some conifers, such as the deodar, produce suppressed branches, in the axils of primordial needles, which are capable of producing new shoots if the terminal shoot be injured, gives rise to the appearance of such stems yielding coppice shoots.

Pines are distinguished by the number of needles in each fascicle, and in the chir the leaves are in clusters of three, whilst in the blue pine they are in clusters of five. Other pines have two leaves in a sheath, as *Pinus Merkusii*. It is found that the needles of several species of pines continue to grow for one or two years after they have been produced.

The number of needles in a fascicle is not, however, constant for the same species, three, four, five, six and seven needles having been found in fascicles of *Pinus excelsa*, though five is the prevailing number.



CHAPTER VI.

FLOWER, FRUIT AND SEED.

As a rule, bracts are more simple in their structure than ordinary foliage leaves, and we find, as we approach the inflorescence of a shoot, that the latter become gradually modified in shape, and the internodes shorter, until the true floral leaves which surround the organs of regeneration are met with.

The bract region.

The above applies chiefly to terminal inflorescences, whilst in lateral inflorescences we frequently find floral axillary buds merely covered with a few protective bracts, and exposing the blossom without any intermediate form of leaf.

As long as the internodes are merely shortened, the transformed foliage leaves are termed *bracts*, but when once those bracts form whorls, each whorl of modified leaves is termed a floral envelope, the two innermost, surrounding the essential organs of reproduction being termed respectively the *calyx* and *corolla*, or *perianth*, when both are combined, and any whorl of bracts which may occur below the calyx is termed an *involucre*.

Any of the floral envelopes shown in the diagram may be repeated, and this repetition may be either normal to the plant in its natural state, as in the case of the numerous corollas of the water lily, or artificial, as in the rose, where several whorls of corolla are produced by transformation of some of the numerous whorls of the *androecium* and *gynæcium*, as the whorls of male and female organs of reproduction are respectively termed.

The calyx may only differ slightly from an involucre, and generally forms the protective sheath of the flower when still in the bud, the involucre, if there is one, being frequently already expanded before the flower-bud opens.

We frequently find showy colours in the petals, and glands con-

taining honey, or odours at their bases. Thus, the corolla serves to attract insects, which we shall afterwards find to be extremely useful in fertilization.

The gynoecium and androecium alone constitute the essential parts of the flower, and are composed respectively of carpels and stamens.

Any one of the whorls referred to may be absent. Thus, in certain willows, the whole flower consists of a solitary carpel, or stamen sheathed by a bract, such simple blossoms generally forming lateral and not terminal inflorescences.

When there is only one envelope outside the essential organs of reproduction, it is termed a *perianth*, as in the case of many monocotyledonous plants, lilies, aloes, &c., and some dicotyledons as *Clematis* and *Anemone*.

We have described the most complete form of inflorescence, containing all the whorls of a perfect flower terminating a shoot, but it is rare to find the main axis of a plant terminating in this way, and this is generally confined to some monocotyledons such as species of *Amaryllis*, tulips and lilies.

The inflorescence in teak and *sál* is terminal, and consists of an indefinite number of flowers. In figs, mulberries and the sun-flower they are more or less crowded together, whilst in roses, the teak, the *sissu*, and in *Leguminosæ*, except in the family of *Mimosæ*, of which the *khair* (*Acacia Catechu*) is an example, each flower is independent of the rest.

As we have said before, the androecium and gynoecium are the true organs of reproduction, and may be either included in the same flower, or separated in different flowers. They may also be in different flowers of the same individual plant, or, on separate individuals. We sometimes find that a particular species has all these kinds of blossom indifferently, as in the *papita* (*Papaya carica*).

Plants where the male and female organs occur together in each flower are termed *hermaphrodite*, as in the *sál*, teak, *sissu*, &c.

Those in which the male and female organs are found on separate flowers, on the same individual, are termed *monœcious*, as the *Pinus longifolia*, figs and mulberries, maize, *Mallotus phillippinensis*, &c.



The date, *Phoenix dactylifera*, is an example of a dioecious plant in which the male and female organs are found on separate individuals. The jhingan (*Odina Wodier*) is also sometimes dioecious.

In case all these kinds of flowers are found in the same species, the plant is said to be *polygamous*, thus, in the European ash we find *hermaphrodite*, *monœcious* and *diœcious* blossoms, and the mango tree is also said to be sometimes polygamous.

Unisexual flowers may be either staminate (*male*), or pistillate (*female*).

A flower is said to be *neutral*, or *sterile*, when it contains no essential organs. Thus, in the sunflower, the outer ray, or *ligulate* florets are frequently neutral, and their corolla is thus larger and more conspicuous than in the tubular perfect flowers in the centre of the inflorescence. In *Hydrangea*, we have neutral flowers, and also in many cultivated plants, such as roses, dahlias, &c., the essential organs are converted into petals. Such neutral flowers will evidently never bear seed.

The object of neutral flowers in a wild state is to render the inflorescence, of which they are generally the most outward members, conspicuous, and attract insects, which convey the pollen from one inflorescence to another. Excess of cultivation, and, on the contrary, poverty of soil, may result in merely neutral flowers being produced; and it is not uncommon in exhausted fields to find wheat, or maize, the ears of which do not contain a single perfect grain.

The absence of seed, however, may be due to non-fertilization, as well as to presence of merely neutral flowers.

The male organs of a flower form collectively the *androcium*, each separate organ being termed a *stamen*, with its *filament*, and *anther*, the latter containing *pollen* in minute *powdery* grains.

Essential organs of plants.

The filament, which is merely a support to the anther, may be absent, and the anthers may be attached to the corolla, or to the pistil, or gynoecium, or to one another, forming a ring around the pistil, as in sun-flowers and other *Compositæ*.

There are numerous forms of anthers, which usually bear two

lobes, one on either side of the filament. In some cases, these lobes again subdivide into two others, the anther being *quadrilocular*.

The pollen escapes from a slit in the anther, termed a *suture*, and in *Berberis* and most laurels, the face of each anther forms a kind of valve, opening on a sort of hinge.

In orchids, the anthers are borne upon the pistil, and are termed *gynandrous*, and in this family, as well as in *Asclepiads*, the pollen grains form masses, termed *pollinia*, which occur in pairs.

Pollen is usually a powdery substance, which when magnified

Pollen. is seen to consist of separate grains, generally of a yellow colour, and of a definite shape for each species. The shape is generally globular, or oval, but in pines and some other species the pollen grains consist of three or more blended cells.

Pollen grains are generally superficially covered with ridges or prominent points, which assist insects in transporting them, and also cause them to adhere to the stigma of the pistil. The pollen grain has two coats, the outer one termed the *extine*, comparatively thick and cuticularised, and to it the surface markings belong, the inner one the *intine*, forming the true cell-wall, being thin, transparent and colourless.

The cavity between the two coats is filled by a viscid substance, composed of a multitude of minute particles, only visible under a high magnifying power.

When wetted, the grains of pollen become distended and sometimes burst, but if the water be slightly thickened by syrup, and the temperature suitable, the inner coat protrudes through the outer one, giving rise to a slender tube, which may attain a length of 2 or 300 times the diameter of the grain, and the richer protoplasmic contents of the grain tend to accumulate at the further and enlarging extremity of the pollen tube. The extine has frequently a number of circular openings closed by lids, through which the intine can emerge.

The collection of female organs in a flower is termed *gynæcium*, and as this is the central organ of the flower, the different carpels which form it are frequently more or less united, as in the orange. They may,

Gynæcium.



however, be separate, as in *Clematis*, or the gynœcium may only consist of one carpel, as in the pea.

In *angiosperms*, each carpel consists of an *ovary* containing *ovules*, or immature seeds, and of a *stigma*, or disc destined to receive the pollen grains, which may be supported by a style, as in peaches. The style, however, is frequently absent, as in the grape, when the stigma crowns the ovary.

The *gynœcium* terminates the axis of a flower except in monstrosities, when leafy shoots protrude beyond a flower, as a rose-bud springing from the centre of a rose, which is sometimes seen. In the caper family, as in *Capparis horrida*, the gynœcium is supported by a long style-like body termed a *gynophore*.

No normal gynœcium is formed in *gymnosperms*; the ovules being merely protected by a scale, and

Naked ovules. fertilized by direct contact with the pollen grains.

In *angiospermous* plants, however, the ovules contained in the cavity of the ovary are only reached by the pollen in the following manner :—the stigma has generally a rough surface, which exudes a sticky substance, and after the pollen grains have rested on it, their position being secured by their rough external surface, they emit pollen tubes which we have already seen may be of considerable length. These pollen tubes penetrate through the tissue of the stigma and style down to the ovules, and by their contact fertilize them, so that the fertilized ovules become true seeds. Any ovules which are not reached by the pollen tubes remain undeveloped.

In order that the ovules of a silver fir, for instance, may be readily fertilized, we find them projecting at the base of the open scales of the young herbacious cone, which by its resinous nature is protected from attacks of birds, &c.

If no pollen falls on the ovules, no further development takes place and the cone withers away, but should the ovules be properly fertilized by direct contact with the pollen grains, the scales and the whole cone increase considerably in size and assume a woody texture, whilst the scales close over the young seeds and protect them from animals by closing the aperture, which, in the undeveloped cone, was open for the reception of the pollen grains.



The cone, which when unfertilized is erect, also becomes pendant in the spruce and in firs, remaining erect in silver firs and deodar.

As in gymnosperms, the floral organs are simplest, it is evident that this order should be separated from those of monocotyledons and dicotyledons, where the ovules are contained in an ovary.

We find in fact that up to a late geological period gymnosperms were the only phanerogamous plants.

The ovules at the base of each scale of gymnosperms are generally two in number, as in pines. But in cypresses there may be as many as twelve ovules.

Darwin and other botanists have shown by experiments and numerous observations, that far better seed

Cross and close-fertilization.

is produced when the pollen from a separate flower, or even from a different plant falls on any stigma, than when it is fertilized by pollen from the stamens surrounding it, and nature has provided for this being done in a number of ways. At the same time, in certain plants, the essential organs are so situated that ovules in each blossom can only be fertilized by its own stamens. The former system is termed cross-fertilization, or *allogamy*; and the latter, close-fertilization, or *cleistogamy*.

Cross-fertilization.

The commoner adaptations for inter-crossing are termed *Proterogyny*, and *Proterandry*.

In the former, as in many *Compositæ*, the stigmas are ready to receive the pollen, before the anthers in the same blossom have matured their own.

In the latter, the anthers mature and discharge their pollen before the stigmas of the same blossom are matured, as in *Plantago*, where the very slender stigmas project from the unopened corolla, in which the anthers are still enclosed.

A few days afterwards, when the stigma has received the pollen, blown on it from neighbouring plants, the corolla opens and the five anthers protrude and give their light pollen to the wind, whilst the stigma of that flower and of all below it on the inflorescence are withered up and past receiving pollen.

Proterandry is common amongst *Compositæ*, as in the *Leptosyne*



maritima. In this case, the ray flowers are pistillate, whilst the disc flowers are hermaphrodite, and from the latter the *adnate*, or united, anthers first protrude and discharge their pollen, after which the style with an enlarged and brush-shaped stigma slowly lengthens, pushing the pollen before it out of the tube and into the way of insects, until it separates into two branches which expose the stigmatic under surface to pollen from other blossoms.

Other adaptations for cross-fertilization are found in nature, of which a complete account is given in Professor Müller's book. I will only mention *dimorphism*, in which the same plant produces some flowers with long stamens and a short pistil, and others with short stamens and a long pistil. It is evident that in their case a bee in obtaining honey from the latter will not touch the stigma of the long pistil, but in entering the tube of the flower will press against the short anthers and carry away some of their pollen attached to its body, which it then conveys to a short pistilled flower. This form of dimorphism is very common in *Primulaceæ*.

Another kind of dimorphism is adapted for close-fertilization, the flowers being inconspicuous, but the

Close-fertilization. plant also producing other conspicuous and much less fertile, though perfect flowers.

This kind of dimorphism is called *cleistogamy*, and is intended to make fertilization certain, while the benefits of inter-crossing are secured from time to time by the conspicuous flowers, which are generally unfertile. Violets afford common example of *cleistogamy*, and about 60 genera of *cleistogamous* plants are known.

All flowers, for fertilization of which the agency of insects is required are termed *entomophilous*. Such

Fertilization by means of insects. flowers are generally showy, scented, and contain nectar or honey at the base of the corolla. Some of the larger blossoms, such as that of the semal, may be fertilized by the action of small animals, such as monkeys, or squirrels, whilst in South America, humming birds take a large share in this work, and it is probable that in India many of our forest trees and gaudy climbers owe their fertilization to birds.

Flowers which attract night moths are generally white, large

and sweet-scented, and their corolla, as in the Moon flower (*Ipomoea Bona Nox*) frequently fades as the sun gets higher in the morning. In the case of many arums, the inflorescence emits a faint foetid odour, resembling decomposing meat, and thus attracts carrion-feeding insects.

We have already seen that pollen grains are adapted for transport by insects, being moist, glutinous, rough, or strung with threads, as in *Oenothera*—the evening primrose.

The pollinia of *Orchidaceæ* and *Asclepiadæ*, as in the *Calotropis gigantea*, called madar, or ak, or evicum in Southern India, have special adaptations for conveyance by insects, as Darwin in his work on Orchids has shown. As an example of a plant absolutely requiring the assistance of insects for fertilization, we may cite the *Vanilla*. This orchid, from Central America, has been introduced into Mauritius, where it is largely cultivated for trade; it also grows fairly well in Bengal and other hot damp parts of India. In its own country, it is naturally fertilized by insects, but in the Mauritius, and in India, none of the indigenous insects have hitherto learnt how to fertilize it, and this has to be done artificially by the cultivator, who with a small pointed piece of wood like a pencil withdraws the pollinia from their position in the flower above the stigma and then brushes them over the stigma of another flower, where the contact bursts the skin of the pollinia and allows fertilization to take place, thus imitating the action of the Central American insects. Unless such mechanical means are used no fruit is produced, the pollen being unable to reach the stigma by natural means.

Plants in which pollen is conveyed from one flower to another by the action of the wind are termed *anemophilous*.

Flowers fertilized by action of the wind.

Most wind-fertilized flowers are unisexual, being either monœcious or

dicœcious.

They are generally dull in colour, of very simple construction, scentless and without nectar. The principal adaptation in their case to ensure fertilization consists in the abundance, want of cohesiveness, dryness and lightness of the pollen.

The abundance of pollen in coniferous forests is very noticeable, and we frequently find isolated trees at a considerable distance



from such forests, covered with yellow grains of pollen blown on them. The coherence of pollen grains in orchids and in *Oenothera* are designed to prevent its dissipation by the wind. In oaks, hemp and conifers, all wind-fertilized plants, and unisexual, and amongst such hermaphrodite plants as many grasses, sedges and *plantago*, the pollen readily separates into detached grains. All these plants are *gregarious*, and it is evident that wind-fertilization is much more certain in their case than in that of plants growing isolated from one another in which, however, insect-fertilization is readily insured by the conspicuousness of their flowers, and by the instinct of the pollen-bearing insects, enabling them to recognize flowers of the same species, which alone are visited at any particular time, so that the danger of hybridizing is avoided.

In anemophilous plants, in order to facilitate the removal of the pollen by the wind, we find the following provisions :—

- (i). The axis of the male inflorescence may be long and pendulous—examples—catkins of the birch.
- (ii). The peduncles of the male flowers are pendulous.
- (iii). The filaments of the anthers are long and mobile, as in all *grasses*, and in *hemp*.

Certain water plants are adapted for fertilization, either below, or on the surface of the water, and may be termed hydrophilous.

When the pollen of one species is applied to the stigma of another, this is termed *hybridization*, and the plants which may spring from hybridized seed are *hybrids*.

Hybridization.

Hybrids are rarely found in nature, though they are artificially produced by gardeners in order to obtain new and striking plants—as hybrid roses, begonias, pelargoniums, &c.

Natural hybrids are chiefly found amongst anemophilous plants, such as willows, of which there are in northern countries a great number of species and varieties.

Hybridization is rendered difficult in such cases by the following causes:—

- (i). The gregarious nature of most anemophilous plants.
- (ii). The greater certainty of fertilization, when pollen of the same species falls on a stigma.

- (iii). Pollen of other genera, or of remote species is generally inoperative.

At Naini Tál, hybrids of the different species of oaks growing there are said to be occasionally found.

Hybrids would be more generally produced were not the pollen of one species, when applied to the stigma of another species, generally impotent to secure fertilization, or, at any rate, not so able to effect it, as pollen from the same species, which has generally a far better chance of reaching it than that from another species.

When gardeners wish to produce hybrids, they cut off all the stamens of the plant while still immature and take every precaution to exclude pollen from neighbouring plants of the same species.

Hybrids are generally sterile, but occasionally produce fertile seed and in this case the plants which spring from them, have a tendency to return to either of the original stocks, which they do in two or three generation.

Gynœcium. We will now proceed to describe the gynœcium, or pistil, in greater detail.

In angiosperms, the carpels may be considered as leaves which by folding up, either *each leaf separately*, or by uniting the margins of adjacent leaves, enclose a cavity termed the ovary, in which the ovules are contained, the latter corresponding to buds, as in the margin of the leaf of *Bryophyllum*.

The exterior surface of the ovary represents the under surface of the carpellary leaf, the apex of which becomes the style and stigma, and the ovules are situated along the margin of the leaf.

Take the simplest case of each ovary being formed by a separate leaf, we find the line of junction of the margin of the leaf turned towards the axis of the plant, and this is really the only suture in the carpellary leaf and is termed the *ventral suture*, to distinguish it from the opposite projection of the midrib of the leaf, which is sometimes, though incorrectly, termed the *dorsal suture*.

A fruit formed in the way we have described from a single carpel is termed *apocarpous*, such as the pod of the pea and bean.

To take another example, we may suppose that five carpellary



leaves around an axis have become united by their margins to form a compound pistil or gynœcium, which will give rise to a *syncarpous* fruit, as shown in the diagram. In this case, the union of the carpels is frequently so complete that, without dissecting, and merely from an inspection of the stigma, it could be decided that it is composed of several carpels.

The gynœcium, when it is composed of several carpels united together, may be termed a *pistil*.

In some cases, the ventral suture, on which the ovules are always situated, is a mere line, but in others, the margins of the leaves forming it are pressed inwards towards the axis, and are then said to form a *placenta*, which may extend to the very axis of the pistil and become united with it.

By absorption of the portion of the placentas along the margin of the carpels, the latter may become separated from them, preserving their union with the axis of the plant, and thus forming what is termed a *free central placenta*, as in pinks and primulas.

When the placentas are attached to the walls of the ovary, as in the poppy, they are termed *parietal*.

Ovules are generally developed along the modified leaf margins, or placentas, of carpels, but in water lilies and gentians, they are formed, without any apparent order, over the whole internal surface of the ovary.

Ovules.

In gymnosperms, the ovules are borne on the face, or at the base, of a carpellary scale, and are not enclosed in any ovary.

The essential part of an ovule is its nucleus, generally enclosed by one or two coats, with a narrow orifice termed the *foramen*, which when closed up in the mature seed is termed the *micropyle*.

The base of the ovule, from which the coats spring, is termed the *chalaza*, and if the original position of the ovule remains unchanged, the point of attachment of the *funiculus*, or stalk of the ovule, will be the chalaza. It frequently happens, however, that the ovules are more or less turned round, or even inverted, in which case, the *hilum* or point of attachment of a seed to the fruit does not coincide with the chalaza. Ovules may be either sessile, or stalked, with a funiculus; they may be solitary, few, or very

numerous. Simple ovules in *Loranthaceæ*, or *Gnetaceæ*, have no coats, whilst coated, or tunicated ovules, are of four kinds—

- | | | |
|-------------------------------|--|------------------------------|
| (i). <i>Orthotropous</i>. | \| | (iii). <i>Amphitropous</i> . |
| (ii). <i>Campylotropous</i>. | \| | (iv). <i>Anatropous</i> . |

In *orthotropous*, or straight ovules, the *chalaza* is at the base and the foramen at the opposite extremity, the whole ovule being straight and symmetrical, and such ovules are better termed *atropous*, which means not turned at all. Such ovules are found in duck-weed and in *Urticaceæ*.

Campylotropous ovules are so curved as to bring the foramen down to the base, and are found in *Cruciferae* and several other families.

Amphitropous ovules are intermediate between the preceding and the following class, the body of the ovules being straight but fixed by its middle, the *chalaza* being at one end and the foramen at the other, but the funiculus is carried partly round the ovule in a ridge termed the *raphe*. This is common in *Leguminosæ*.

Anatropous ovules are commonest of all and are straight at maturity, the foramen being opposite to the *chalaza* and close to the point of attachment of the funiculus to the ovary, and the *raphe* being longer than in the previous kind.

In angiosperms, the embryo originates as follows :—A grain of

Embryo. pollen resting on the stigma emits a tube,
which penetrates the style, if one exists,

through its loose conducting tissue and reaches the cavity of the ovary, entering the foramen of one of the ovules so as to reach the nucleus. Meanwhile a cavity, termed the *embryo sac*, formed by the enlargement of a single cell, or of several cells, in the tissue of the nucleus, forms near the apex. On this, the pollen tube rests, and its protoplasmic contents are transferred to a globule of protoplasm, contained in the embryo sac and termed the *embryonal vesicle*. This, then, takes a definite shape, acquiring a wall of cellulose and becoming a cell. This cell sub-divides into two cells, and the lower of these into two again, and so on, forming a chain of cells termed the *suspensor*.

The terminal cell of this chain then sub-divides, producing a mass of cells which form the embryo, and the suspensor generally disappears. It is attached to the radicle of the embryo, which always



points to the foramen. In certain cases, two or more embryos are produced and this is not uncommon amongst gymnosperms.

The production of two or more embryos is termed *polyembryony*; it is occasionally found in mistleto, in sandal, and is not uncommon among gymnosperms.

In onions, oranges and a few other plants, several embryos are sometimes found quite independent of the embryo sac and of fertilization. These embryos are produced by a kind of budding termed *apogamy*.

The fruit consists of the matured gynoecium of one, or of several carpels, as the case may be, and includes

Fruit.

any other part of the flower, or inflores-

cence, which may be joined to the former.

Fruits may be classified as follows :—

- (i). A matured ovary.
- (ii). A matured cluster of ovaries.
- (iii). A matured ovary, or cluster of ovaries, with the calyx and other floral parts attached to it.
- (iv). A ripened inflorescence.

The 1st class forms simple, or *apocarpous* fruits, which may be distinguished as follows :—

- | | |
|------------------|----------------------|
| (i). Dry fruits. | (ii). Fleshy fruits. |
|------------------|----------------------|

Dry fruits may be *dehiscent* or *indehiscent*, the former being many-seeded, while indehiscent dry fruits are naturally one-seeded, or in many cases become so by suppression of superfluous ovules. The pomegranate is an exception to this rule.

In dehiscent dry fruits, as in most leguminous pods, the covering splits so as to cause the dispersion of the seed, and in the maljhan this takes place with considerable force and a report, the seeds being dispersed in all directions. In indehiscent dry fruits the seed becomes exposed by the decomposition of the coats of the fruit.

All fruits formed from a single carpel are termed *apocarpous*, whether dehiscent, or indehiscent. Amongst indehiscent apocarpous fruits, we have the *samara*, as in elms and maples; or *akene* as in *Ranunculaceæ*. Such fruits are generally one-seeded.

The grain of wheat, barley, oat or maize is another indehiscent fruit termed *caryopsis*. It differs from an *akene*, in that the seed

completely fills the cavity of the fruit, so that the testa cannot be easily distinguished from the *pericarp*, or covering of the ovary.

Fleshy fruits may be either fleshy throughout, or with a firm rind, or shell, or fleshy externally and hard internally.

In indehiscent fleshy fruits, as the mango, the seeds are separated by some animal or bird eating the *mezocarp* and leaving the hard *endocarp* enclosing the seed on the ground. This then absorbs moisture and eventually opens, so as to allow the passage of the germinating embryo.

Such fruits are too weighty to be conveyed to a distance from the parent tree except by some animal, and they are generally of conspicuous shape and colour compared with the inconspicuous *achenes* and *samaras* and other fruits, which may be conveyed by the wind.

Fruits resulting from a mature cluster of ovaries are termed *aggregate*, as the strawberry.

Fruits composed of several united carpels are termed *syncarpous*, as the orange and pear.

In certain kinds of *syncarpous* fruits, although at first composed of several ovaries each containing more than one ovule, yet by the suppression or unequal development of some of the parts, the mature fruit appears to be simple. Thus, in acorns, the ovary consists of three cells each containing a pair of ovules, whilst in the fruit we find a single cavity with one ovule. Thus, two ovaries and five ovules are suppressed, traces of them being sometimes discoverable within the *pericarp*. *Syncarpous* fruits may be dry and dehiscent, as the *capsule* of the poppy, or may be fleshy and indehiscent, as the orange. *Syncarpous* fruits frequently contain parts of the calyx and are then termed *anthocarpous*, as in the apple and the *guáva*; in the *cashew* and marking-nuts, the fleshy part of the fruit is a disc formed by the peduncle.

A collective, or aggregate fruit results from an inflorescence, as in the pine-apple, the mulberry and the fig.

The *pericarp* besides serving as a protection to the seeds, may also by means of certain appendages, or outgrowths from it, assist in their dissemination.

Winged fruits. Fruits with wings are not uncommon as in *sál* and the different species of *Dipterocarpeæ*, which are so common in



Burma. We have already referred to the samara of elms and maples.

The fruits of some terminalias, as the sain (*Terminalia tomentosa*), and the arjun (*T. Arjuna*), have five lateral wings.

The wings in the fruit of some *Compositæ* are due to the subsequent growth of the calyx forming a *pappus*, or hairy appendage, on the summit of each akene. *Compositæ* without a calyx form no pappus. Many grasses have also winged fruits.

We find certain mechanical movements for dispersing seeds of fruits due to the elasticity of the pericarp. This is well seen in the balsam and geranium, in certain species of *Cucurbita*, and in the pods of the maljhan, &c.

Owing to the dispersion of coniferous seeds by the rupture of the cones, it is advisable to collect the latter before they open, and disengage the seed by artificial heat, and in Europe large establishments, termed in France, *sécheries*, are kept up for the purpose. We may note that the cones of the deodar and silver firs are erect and break up on the tree, whilst those of the pines are pendulous when mature, and open out to allow the seeds to escape, the cones remaining on the tree sometimes for several years. The spruce cones also open out on the tree, but do not remain long after the seeds have escaped.

Some fruits are furnished with hooks, as in *Martynia diandra*, a plant common in the Dún, but introduced from Mexico. By means of these hooks, the fruit becomes attached to animals and birds, which transport them to considerable distances. The various kinds of spear-grass have barbed hooks which penetrate the skin in a disagreeable manner.

When the hooks are small and numerous on fruits, the latter are known familiarly as *burrs*, as in docks. Other plants have sticky exudations round their fruits, which have a similar action to that of hooks.

In the case of the cocoanut, we find that the fruit, rendered buoyant by its hollow cavity and protected outside by its tough fibrous covering, can be conveyed to immense distances by the sea, and remains unbroken, even when dashed against a rocky or shingly coast.

Special adaptations.



Owing to these properties of the cocoanut, a new coral island is no sooner formed in the Pacific Ocean, than cocoanuts washed ashore give rise to a fringe of cocoanut palms along its coast.

Many fruits, as we have already seen, owe their dissemination to their pulpy, fleshy, or sweet mezocarp; these are eaten by birds, or animals, which drop about the hard indigestible endocarps.

Cherries and other stone fruits are examples of this, whilst in roses or figs, the hard *akenes* are contained in fleshy pericarps composed of the calyx tube, or of the peduncles of an inflorescence.

This mode of dispersion is very common in figs, and it is owing to it that the banyan and other figs spring up in hollow trees and old masonry.

Excessive production of fruit, as in the case of many orchard trees, such as cherries and plums, may

General remarks. completely exhaust the tree in a single year.

When, therefore, we wish to obtain large supplies of fruit, we must remember to supply rich manure before the blossoming season.

It is also sometimes found, especially in the case of apple and pear trees, that certain of these have a tendency to produce mere foliage shoots without any blossom. In this case, it is better to check the vigorous vegetation of the tree in order to ensure the production of floral buds. This may be done by pruning in the midst of the growing season, or by *root pruning*, both of which processes tend to arrest the formation of foliage buds. Plenty of space should also be left for the crown and root system of fruit trees, and for these, it should be remembered that the long bole so admirable in a forest tree is quite out of place, and the crown should generally be pruned down to a reasonable distance from the ground. We all notice amongst forest trees that those growing in poor soil or in exposed places, as well as those that have suffered from forest fires, lopping, and other bad treatment generally bear fruit when much younger than vigorous trees of the same species growing in a dense forest. In well-stocked forests of fir and deodar, we frequently fail to obtain any seed until the crowns of the trees have been isolated by the removal of some of their neighbours and their



upward growth checked, whilst the older part of the crown being exposed to light may be expected to produce numerous floral buds.

The seed is a fertilized ovule enclosing the embryo, and consists of a nucleus covered by integuments, or coats, of which there may be two, one, or none at all. Occasionally, an accessory coat appears after fertilization, and certain appendages may also be produced.

The nucleus may be composed of the embryo alone, or may contain the endosperm as well.

The outer coat of the seed is termed the *testa*, and the inner, if one exists, the *tegmen*. The two characteristic appendages of the *testa* are the *wings* and the *coma*, both of which facilitate the dispersion by the wind of seed dehiscent fruits. As examples of winged seeds we may note those of *Calosanthus indica*.

In cotton, the seed is covered with the long soft hairs of the coma.

In many species of *Apocynaceæ*, as in *Wrightia tomentosa*, the seeds are surmounted by feathery tufts of hair resembling the *pappus* of the fruit of *Compositæ*.

The seed of the cotton tree (*Bombax Malabaricum*) is also hairy.

Other structures are formed on the testa to retain the seed in its place after reaching the ground, it may be covered with short hair, or with mucilage, as in the seeds of the common cress. Other seeds, such as those of *Abrus precatorius*, are of striking colours to attract birds.

When a third fleshy covering is produced, as in the seeds of the *Euonymus* and pomegranate, and is also frequently bright-coloured, or sweet flavoured, this is termed an *aril*. Mace is the dried aril of the nutmeg. In this way also birds and animals are induced to carry off the indigestible seeds.

When the inflorescence is terminal, it is evidently the new shoots of the year which produce the buds in the axis. flower buds, as in the sandan (*Ougeinia dalbergioides*) and dhak (*Butea frondosa*), where we may find a whole tree covered with blossom, to the entire exclusion of leaves, which only appear after the blossom has fallen.

In woody plants with indefinite inflorescence, however, we may find flower buds, produced in one year and opening in the succeeding one, so that they are only on the second year's wood. To take the pear as an example, the lower buds are destined to produce fruit in the ensuing spring and in order that they may obtain their full share of nourishment, the yearling shoot should be pruned off above them during the season of rest, which may be ascertained to be the case by watching for the period when the tree is perfectly leafless. Manure should at the same time be given. In case this pruning is not effected, the fruit buds may either fall off, or remain dormant, the sap flowing to the yearling buds above them.

In some other plants, as in the jack tree and the gular (*Ficus glomerata*), the inflorescence sometimes springs from dormant buds on the main stem and branches of the tree. The fruit of the jack sometimes weighs upwards of 20 lbs., and could not be otherwise supported.

In the *asoka* (*Saraka indica*) the blossom is also frequently produced from dormant buds on the stem and branches.

We have already seen that buds appear normally at the end of the terminal shoots and in the axils of leaves, in some cases, as in the plane (*Platanus orientalis*), being so covered by the sheath of the leaf as not to be visible unless the latter be removed. Buds are frequently protected by scales during the season of rest, and as each of these scales is really a leaf we may expect to find minute buds at their axils. These scales are crowded together on extremely reduced internodes, so that besides the normal buds, a number of minute dormant buds surround them.

Unless these become imbedded in the bark, so as to lose their vitality, they form a circle of dormant buds round the stump of a tree, ready to produce numerous shoots, after it has been felled, or pollarded.

If we make a transverse section of a bud, and we may take a common cabbage as a good example of an enlarged bud, we find that the scales and leaves of which it is composed are arranged in special ways, which are characteristic for each species. This arrangement of foliage leaves in a bud is termed *vernation*, dis-



tinguished from *æstivation* in the case of floral leaves. The terms *præfoliation* and *præfloration* are, however, preferable. There are many terms for the ways in which leaves are folded in buds, as, *plicate*, *convolute*, *revolute*, *involute*, and *circinate*. These terms will be readily understood from the annexed diagrams.

Some buds, as in *Verbenaceæ*, including the teak, are naked, the foliage leaves not being protected by scales. These are commoner in tropical countries, as scales form a necessary protection from winter frosts in colder countries. They are large and of regular growth in the horse-chestnut, and even persist for sometime after the bud has opened. In silver fir they form a little cap which is thrown off by the opening bud.

Besides the normal axillary buds, we frequently find one or more smaller ones below them. Such buds are termed *accessory* buds, and may be situated one above the other, when they are termed *superposed*, as in the honey-suckle, or in *Cordia Myxa*, or be placed side by side, as in certain maples and willows, when they are termed *collateral*.

Generally the normal axillary bud is strongest, and the accessory buds remain dormant, but it sometimes happens that the latter produce shoots, whilst the former remains dormant. When accessory or lateral buds remain dormant, a secondary foliage may be produced from them in case the first be destroyed by fire, insects, or other causes. If not called into action in this way, the accessory buds may remain dormant, and thus assist in the production of stool or pollard shoots. When a terminal bud is produced, it is generally the strongest, but in many cases, the upward growth of a shoot is continued by an axillary bud. Floral leaves sometimes produce axillary buds, but these are monstrosities, sometimes occurring in garden pinks.

CHAPTER VII.

SOME NOTES ON CRYPTOGRAMS.

The lowest family of cryptogams is termed *Thallophyta*, including sea-weeds, or *algæ*, fungi and lichens. The body of the plant consists of an expansion termed a *thallus*, in which the stem and leaves are not distinguishable. Some of these plants consist of a single cell, and in their higher forms even, thallophytes are composed of a mass of cells, either uniform in structure, or, in which the external and internal cells differ very slightly. In the lowest form of thallophytes, no sexual reproductive organs have yet been discovered, and the plants appear to multiply simply by budding. In the higher forms, we find three modes of sexual reproduction :—

(i). In which the two elements are similar in size and appearance; their union being termed *conjugation*, and by it a *zygote*, being a specialized cell, filled with protoplasm, which may grow and produce asexual spores is produced.

(ii). The difference between the two reproductive cells is considerable—the *germ* cell, termed the *oosphere*, being very much larger than the *sperm* cell, termed the *antherozoid*. After the union of one, or two, of the latter with one of the former it becomes fertilized, and is then termed an *oospore*.

(iii). Lastly we have a *carpogonium*, a special organ of fructification, and from which the *sporocarps* containing the *oospore* grow.

Owing to these three kinds of reproduction, thallophytes are divided into four classes :—

- (i). *Protophyta*, without sexual reproduction.
- (ii). *Zygosporeæ*.
- (iii). *Oosporeæ*.
- (iv). *Carposporeæ*.

When merely buds are produced to multiply the species, this



is termed *apogamy*, and is common in the case of ferns, as well as being universal in protophytes.

Production of little bulblets in the Egyptian onion in place of seeds, and the budding on the leaves of *Bryophyllum* illustrate this mode of reproduction.

Protophytes are subdivided into two sub-classes, in the first of which the plants do not contain chlorophyll,

Protophyta.

as in the yeast plant ; whilst in the second, they contain chlorophyll, as in many species of water weeds.

All protophytes without chlorophyll are necessarily saprophytes, or parasites.

The yeast plant is one, which as we have already seen, multiplies with great rapidity in malt liquor by perpetually budding, as long as sufficient nitrogen and other nutriment is afforded to it. Such plants are termed *vegetable ferments*, and assist in converting sugar into alcohol.

Bacteria are minute microscopic plants found in putrifying matter, and also in the bodies of animals, under certain conditions. Various forms of disease, such as malarial fever, small-pox, &c., result from the presence of these *bacteria* in the blood.

As examples of *zygosporeæ*, we may take species of *Protocarpus*, as in the green scum on the bark of trees.

Zygosporeæ.

During a part of their life the cells of *Protocarpus* have a power of motion, swimming about in the water in the form of naked bits of protoplasm, which afterwards come to rest and acquire a cell wall.

Zygosporeæ have also two subdivisions similar to those of protophytes, *i.e.*, furnished with chlorophyll, or without it.

In the former class, we find various algæ of the sea, or of fresh water, and the remarkable genus of *Pandorina*.

Oosporeæ may be similarly subdivided. It contains numerous algæ and such parasites as *mildew*, &c.

Oosporeæ.

Amongst the algæ of this order, some attain large dimensions and grow in immense quantities ; *Macroceps* of the Southern Ocean attaining a length of 500 feet.

In a portion of the Atlantic Ocean, masses of sea-weed are found floating on the surface over an area of hundreds of square miles.

Carposporeæ include the higher forms of algæ and fungi, also of lichens and the *rust* of wheat, a black-coloured parasite. This order is also sub-

divided into forms with, or without, chlorophyll, the former containing a number of fresh water and sea weeds, while the latter consists principally of fungi.

In the mushroom (*Agaricus campestris*) for example, from the true spore, the *mycelium*, a vegetative body, is developed, consisting of a number of many branched filaments either covering or penetrating the body on which it is growing.

The *mycelia* of lichens cover the bark of a tree, or the surface of a rock, while various forms of wood-rot permeate the tissues of living, or dead vegetable tissue.

The *mycelium* may only exist for a short time, or may continue to grow for years, merely reproducing itself by budding.

In all cases, in which the life history of a fungus has been thoroughly traced under favorable circumstances, the *mycelium* at length develops sexual organs within a *carpogonium*.

Fairy rings in grass are due to the growth of *mycelia* from a central point, leaving its dead portions inside the ring formed by its actually living parts.

Where growth is still in progress, the *mycelium* absorbs its nourishment from the grass roots, and we have a zone of rusty-coloured grass, whilst inside this ring, the grass manured by the dead *mycelia* is of a bright-green colour and forms the fairy ring by contrast with the rusty-coloured grass beyond it.

It often happens that *mycelia* grow inside the living tissues of plants, as for instance in the needles of the spruce and chir, and in the wood of the tûn. In the former case, in the Himalayan spruce fir, the bright yellow *carpogonia* of a fungus burst through the needles in the form of yellow-coloured tissue, from which the spores escape. The *mycelia* growing in the needles absorb all their nourishment and kill the terminal shoots of the branches, which first turn yellow and then black, falling into powder.

It is probable that the spores find entrance into the needles through the stomata. The fungus which attacks the needles of *Pinus longifolia* and *Pinus excelsa* is a species termed *Peridermium Pini*, which first grows on a herbaceous plant, in Europe on



a *Senecio*, and kills the leaves of the latter. The spores escaping from these dead leaves pass into a pine needle through the stomata, in which they develop into a mycelium, and the presence of the parasite is soon shown by the yellow *carpogonia* which emerge from the needles in the form of little yellow plates.

This disease sometimes attacks the wood of pines, in which case, the stem assumes a quite abnormal shape, as all growth ceases at the points attacked.

The mycelium of another fungus is extremely common on the tûn, in Dehra Dûn, and its presence may be recognized by the small tufted yellow leaves in the attacked branches, which generally dry up after a few years. Other parasites, such as *Trametes radiciperda*, attack the roots of conifers, and these are speedily fatal.

The *Hysterium Pinastri* shows itself in the form of little black spots on the needles of pines; as a rule this only attacks young plants; and is chiefly to be feared in nurseries, where it may destroy a whole year's crop. The best precaution to take, when this parasite appears, is first to change the site of the nursery, if possible, or to grow the plants in little isolated patches.

Agaricus melleus has *carpogonia* in the form of yellow toadstools springing from the base of dead and dying trees, and is very common in Europe, it spreads from tree to tree by its underground *rhizomorphs*, mycelia consisting of dark purple black strings, which spread in the wood of roots, and thus hundreds of spruce firs in Bavaria have been destroyed. In this case, and in that of *Trametes*, trenches may be dug round infected trees to prevent the spread of the infection. *Polyporus sulphureus*, is a wound parasite, the spores of which enter the wood of trees by some wounded surface, a cut branch, torn bark, &c., it forms tiers of bracket-shaped bodies, yellow below, orange or vermilion above, which project from diseased trunks. The mycelia of the dry rot in timber, *Merulius lacrymans*, may be seen in cellars and other damp places, passing from badly attacked planks, or beams, and across brick-work to sound timber which it then infects.

The greatest danger exists from the light spores of the *Merulius* being carried about, and all diseased timber in a yard or building should be removed and burnt to avoid the danger of infection.

In clearing ground for cultivation, as for tea gardens, it is far better to dig out stumps of trees, than to leave them in the ground, as they only serve as centres for the propagation of fungi, and in Assam, tea bushes are frequently found killed all round an old stump by the mycelia of fungi spreading from the latter. It is easy enough to cut the roots underground and use the stem as a lever to extract the stool of a tree.

Bryophyta may be distinguished from *thallophyta* by alternation of generations taking place. The

Bryophyta. first of these is sexual, consisting of a *thallus*, bearing *antheridia*, and *archegonia*, corresponding to stamens and pistils, and from the latter, after fertilization, a *Sporogonium* bearing the fertile spores arises. This order includes mosses and other similar forms.

Mosses contain chlorophyll and bear little green scales along the axis, which serve as leaves, and on the leafy shoots *antheridia* and *archegonia* are developed. Each of the latter contains an *oosphere*, which when fertilized gives rise to the moss-fruit, or *sporogonium*, terminating in a capsule covered by the *calyptra* and enclosing the spores. These after escaping from the capsule germinate, and give rise to many branched cell filaments, termed *Protonema*, from which the proper moss stems spring. The moss fruit is not really continuous with the rest of the plant, but grows on it, like a parasite.

Mosses are more abundant in cold countries and in higher altitudes. In Europe, the ground under dense forests is frequently covered ankle deep with many species of mosses, which thrive on the decomposing leaves, and would disappear if subjected to bright sun light, which would dry them up, as being cellular plants, they are without conductive tissue. They are found in the Dún in moist shady places.

Frequently, in a forest we may at once ascertain the north, as all the trees have their bark facing that direction covered with mosses and other cryptogams, which grow less readily on the southern surfaces of the trunks, as their cellular tissue is so easily dried up by insolation.

Cryptogamous plants generally are fond of moisture, and the rocks and trees on the southern slopes of the Himalayas become covered with a dense coating of these plants during the monsoon,



which the first few days of bright sunshine at its termination suffices to dry up, when the spores and rhizomes of the dried plants remain dormant until the next monsoons.

Pteridophyta or vascular cryptogams.

This is the highest order of cryptogams, and includes *Equiseta*, ferns, *Lycopodia*, and some other classes.

Species of *Equiseta* attained large dimensions in old geological times, their remains being found in coal beds. At the present day, the different species of *Equisetum* chiefly grow underground in the form of branching rhizomes, these send up green shoots with vascular bundles surrounding the pith. These may be 5 or 6 feet high, and are of small diameter. The upright shoot becomes a hollow cylinder interrupted by transverse plates at the nodes. This is a form of great mechanical strength with little expenditure of material. The outer surface is marked with ridges and furrows, which combined with silica, always contained in the leaves and stem, renders them useful for polishing.

The branches are little green filaments given off in whorls at the nodes. The leaves are funnel-shaped sheaths investing the stem, producing longer or shorter teeth. The rhizomes develop roots at their nodes and gives rise to buds which produce roots, or foliage and fertile shoots. The barren shoots contain chlorophyll in their cortex, and branch freely at the nodes. The reserve material they prepare goes to nourish the rhizomes, which may live for long periods. The fertile shoots have little or no chlorophyll, and bear sporangia, which are situated on the under-side of numerous hexagonal plates on slender horizontal stalks. These plates unite to form the cylindrical fructification of the *Equisetum*, at the summit of the fertile shoots. The spores on escaping from the sporangia produce *prothalli*, which contain chlorophyll and send out root hairs and bear *antheridia*, or *archegonia*. The *antherozoids* are set free from the *antheridia*, and they fertilize the central cell of the *archegonium* and produce an embryo, which grows up into the mature plant.

In ferns, we frequently find underground stems, or rhizomes,

Ferns.

which ascend obliquely and are completely covered with the stumps of dead fronds, from the bases of which, numerous roots arise. The fronds are the



most conspicuous parts of these plants, especially in tree ferns, which form erect woody stems generally from 10 to 20 inches in girth, and occasionally attaining a height of 50 feet. The fronds resemble the leaves of angiosperms, they contain chlorophyll, and are organs of nutrition to the plant, besides that fertile fronds bear the sporangia. These are either on the under-surface, or on the margins of ordinary fronds, or, as in the *Osmunda*, on metamorphosed portions of them. They are small and very numerous. The fern spores when sown in a suitable manner germinate and produce prothalli.

Ferns frequently form an undergrowth in dense forests on sandy soils. Some are climbers, whilst tree ferns abound in New Zealand, British Sikhim and other moist parts of India. The fronds unroll from a circinate vernation. They are frequently very much subdivided and of large size. The fibro-vascular bundles in ferns have already been described. The prothalli of ferns are heart shaped, entirely cellular, and rich in chlorophyll, and contain archegonia and antheridia, whilst from their surface nearest the substratum on which they are growing, their epidermal cells give out long root hairs. The oospheres in the archegonia, after fertilization give rise to new fern plants, which spring from below the prothalli, developing stems and roots, as in the perfect plant.

Lycopods, or club mosses, are larger and stiffer than ordinary mosses and have a vascular axis. They

Lycopods.

always branch in a dichotomous manner, and are found in mountainous and stony, wet places. They formed large trees in the *Carboniferous* period, named *Lepidodendron*.

The prostrate creeping stem of a *Lycopodium* is very leafy and much branched. From the under surface arise the roots, and from the upper surface upright fertile shoots, generally ending in two fertile spikes. The minute spores are applied to various purposes, they contain a quantity of resin and are greasy at the surface. The resinous quality renders them highly combustible, and so they are used to represent lightning at theatres. Owing to their greasy nature they are used for dusting over pills to prevent the pill from touching the tongue. Selaginella is a common Indian example of an allied class.

It is interesting from its reproduction resembling that of the



higher plants, the sporangia producing two kinds of spores, *microspores* and *macrospores*, the former, which are much the smaller of the two, become subdivided into a number of antherozoids, whilst the macrospore, if properly sown, produces a prothallus separated by a diaphragm from a mass of large-celled tissue resembling the endosperm of higher plants. In this prothallus, archegonia appear, each containing an oosphere, and these latter, when fertilized, each produces an embryo growing within the endosperm, and from which the perfect plant is gradually developed.

It is thus clear that, the reproduction of the higher forms of cryptogams resembles that of angiosperms, in which the pollen grains are the microspores and the embryo sac, the macrospore, but the chief difference between these two great divisions of the vegetable kingdom lies in the fact that the oosphere in angiosperms and gymnosperms is buried in a mass of tissue, so that it must be reached by the growth of the pollen tube, whilst in cryptogams, it is exposed to the action of mobile antherozoids, which reach it through the medium of water.

Hence we always find mosses, ferns, selaginellæ and other cryptogams growing in places, which however dry they may be, at certain seasons of the year, are thoroughly moist for more or less prolonged periods, so as to allow time for their complicated processes of reproduction to perfect themselves.

In angiosperms and gymnosperms, on the contrary, we have already seen that the action of the wind, or of insects, is generally required to convey the pollen grains to the neighbourhood of the embryo ; and moisture is only required to produce the pollen tube.

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